

# 3

## The Coeur d'Alene System

### OVERVIEW

The Coeur d'Alene River basin is a large complicated system with tremendous topographic, hydrologic, and biological variability. This chapter summarizes the components of the Coeur d'Alene system that the committee considers most important in understanding the system and evaluating the likely effectiveness of proposals for the basin's cleanup. The information presented here forms the basis for the analyses contained in the subsequent chapters.

The area covered by the proposed cleanup efforts being reviewed includes the Coeur d'Alene River basin (outside of the Bunker Hill box), Lake Coeur d'Alene, and the upper reaches of the Spokane River, which drains Lake Coeur d'Alene (see Figure 3-1). The total length of this system is 166 miles (267 kilometers [km]), and the study boundary includes an area of approximately 1,500 square miles (almost 4,000 km<sup>2</sup>) (URS Greiner, Inc. and CH2M Hill 2001a, p. 4-9). The final project area, however, is much smaller, including only the contaminated portions of the basin, lake, and Spokane River.

### Socioeconomic Considerations

Historically, the growth and vitality of the communities of the Coeur d'Alene River basin have been closely linked to the natural resources of the region. The most obvious example is the relationship between the changes

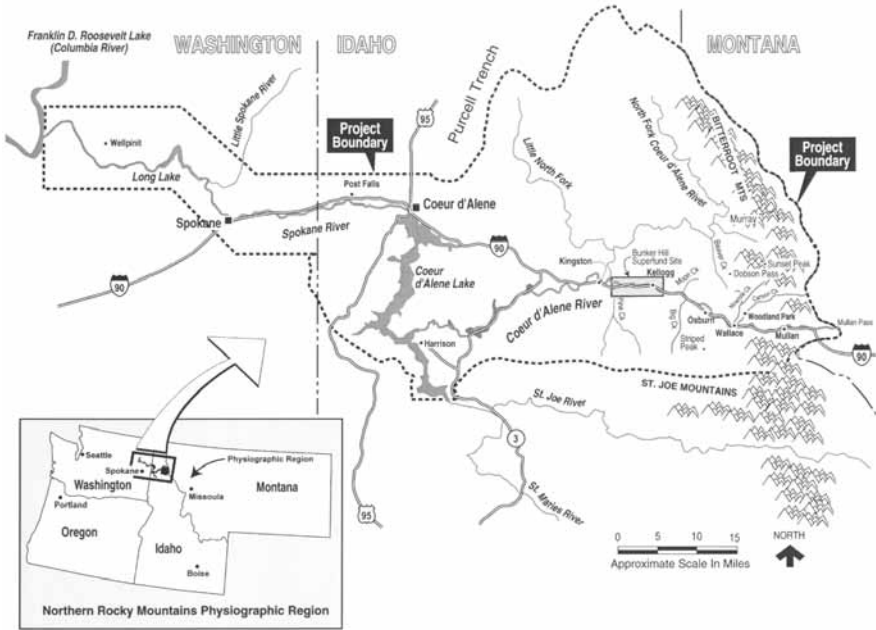


FIGURE 3-1 Map of the Coeur d'Alene River basin. SOURCE: URS Greiner, Inc. and CH2M Hill 2001b.

in the mining industry over time and the status of the associated mining communities. The forest resources have supported the lumber industry, and Lake Coeur d'Alene is developing a strong recreation and tourism economy. In addition, some members of the Coeur d'Alene tribe historically relied on the resources of the basin to support a subsistence lifestyle.

There are also important relationships between the socioeconomic attributes of the basin communities and potential risks from environmental contaminants. The mining communities have large stocks of older housing. Older houses are more apt to have lead-based paints, which constitute an indoor source of lead exposure. They typically also have greater air infiltration rates than new houses, which can result in larger inputs of airborne contaminants to the indoor environment. Households in the basin tend to have low incomes, and basin communities exhibit high poverty rates. Research on the relationships between blood lead in children and environmental and social factors has shown that blood lead levels (BLLs) tend to increase as measures of socioeconomic status decrease (Bornschein et al. 1985). A final factor affecting human health risks for the types of contaminants found in the basin is the age of the people exposed. Very young

children (less than 5 years old) are most susceptible to the neurological effects of lead (Koller et al. 2004).

Topography

The Coeur d'Alene River basin is located in the western part of the Northern Rocky Mountain physiographic province, extending from the Bitterroot Mountains that run along the border between Idaho and Montana westward to Lake Coeur d'Alene, which lies near the border of Idaho and Washington.

The river basin consists of the South Fork (299-square-mile [774 km<sup>2</sup>] drainage area) and the larger North Fork (895-square-mile [2,318 km<sup>2</sup>] drainage area), which merge 4 miles above the community of Cataldo. Downstream from this confluence is the main stem of the Coeur d'Alene River, which flows 29 miles (47 km) to Lake Coeur d'Alene. The lake then drains through the Spokane River (see Figure 3-2).

The river basin contains three topographical types differentiated on the basis of their stream gradients and floodplain characteristics. The first type includes the upper reach of the South Fork from the Bitterroot Mountains to the town of Wallace, the upper reach of the North Fork, and all the

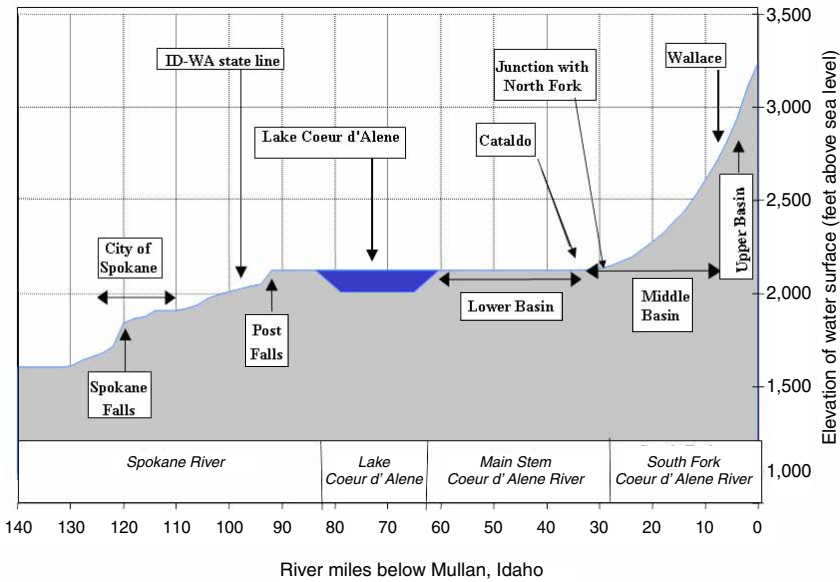


FIGURE 3-2 Longitudinal profile of Coeur d'Alene-Spokane River drainage. SOURCE: Box 2004.

tributaries of the South and North Forks. These areas, which typically have steep stream gradients and limited floodplains, are termed the upper basin.

The middle reach of the South Fork of the Coeur d'Alene River from Wallace to Cataldo and the middle reach of the North Fork are the second type of stream topography. In these reaches, collectively called the middle basin, the valley has wider floodplain areas bordered by steep valley walls, and the river gradient is more moderate.

The third type is the lower basin, containing the main stem of the Coeur d'Alene River, which runs from Cataldo to Harrison. In this reach, the river system is actually deltaic and the channel is backflooded by the waters of Lake Coeur d'Alene. Here, the river channel takes on a meandering pattern and, for most of the year, has an imperceptible gradient. The floodplain in this section is quite broad containing wetlands, "lateral lakes," and agricultural lands.

At the bottom (western end) of the lower basin, the Coeur d'Alene River flows into Lake Coeur d'Alene. This large and relatively deep lake is the ultimate sink for much of the contaminated sediment being carried down the Coeur d'Alene River.

The Spokane River drains Lake Coeur d'Alene at its north end. A dam constructed at Post Falls near the beginning of the river controls the water level in the lake. The Spokane River flows westward through the city of Spokane and on to the Columbia River at Lake Roosevelt behind Grand Coulee Dam.

Although the system can be divided into these different components on the basis of topography, it is important to remember that this is one interactive system, and it needs to be viewed as such if cleanup plans are to be successful (for an example, see Box 3-1).

## Climate

Data concerning the climate in the Coeur d'Alene River basin are limited. The Coeur d'Alene River basin is typical of a "highland climate" with substantial variations in temperature and precipitation both from year to year and from higher to lower elevations.

## Temperature and Precipitation

The upper basin experiences very high precipitation, averaging 55 inches (1.4 meters [m]) a year, of which 75-80% is in the form of snow (Isaacson 2004). The U.S. Forest Service has recorded up to 100 inches (2.5 m) of precipitation, with the depth of snow exceeding 18 feet (5.5 m). In the middle basin at Kellogg, during the 30-year period of record, the highest temperature recorded was 111°F (44°C), and the lowest was -36°F

**BOX 3-1 Riverine Systems and Fish**

The fish species in the Coeur d'Alene River basin represent a valuable resource for recreation and subsistence living. As in most Rocky Mountain headwater streams, salmonids, including various species of trout and salmon, are a dominant species, but a number of other important species are found there as well (CH2M-Hill and URS Corp. 2001, Table 2-3).

For many of these species, the river continuum theory (Vannote et al. 1980) demonstrates the importance of the entire hydrologic system to the health of their populations. In general, as mountain rivers grow in size, the size of the fish, the number of small fish, and the range in fish sizes all increase (Minshall et al. 1992). The nature of the food available to the fish and the biotic and abiotic interactions change along the path of the river as it moves downstream. As a river becomes larger, there are more microhabitats and more pathways for obtaining food, and, as a result, the range of sizes and the number of species generally increase downstream.

The river continuum is particularly important to salmonids in that upstream migration patterns are an integral part of their usual life history pattern (Baxter and Stone 1995), and this pattern links fish in a lower subbasin to habitat, prey abundance, and type in an upper basin. For example, in the Coeur d'Alene River basin, cutthroat and bull trout adults inhabit a wide variety of river habitats; however, they return upstream to tributary streams to spawn (Woodward et al. 1995).

Connected habitats in the Coeur d'Alene basin tie upstream biotic communities to those in downstream segments (Vannote et al. 1980; Minshall et al. 1992). High-quality riparian habitats and substrates for benthic invertebrates (an important food source) lead to "quality" trout stream fisheries.

For all these reasons, establishing high-quality riparian zones and desirable channel characteristics, as well as improving water quality along the length of the Coeur d'Alene River and its tributaries, is important to establishing and maintaining healthy and diverse fish populations.

(-38°C). The average was 47°F (8.3°C) (URS Greiner, Inc. and CH2M Hill 2001b, p. 3-2).

The average annual precipitation at Kellogg was 31 inches (0.79 m). The town of Wallace, at a somewhat higher elevation, had an average of 37 inches (0.94 m). Most (70%) of the precipitation occurs in the form of snow in October through April. As an indication of how variable the weather can be, the minimum annual snowfall—16 inches (0.41 m)—occurred in 1995, and the maximum—124 inches (3.15 m)—occurred the following year. The average annual snowfall over the period of record was about 52 inches (1.32 m) (URS Greiner, Inc. and CH2M Hill 2001b, p. 3-2).

Normally, the snowfall melts off slowly in late spring and early summer. However, this area can experience warm winter Pacific storms that bring a sudden onset of above freezing temperature and heavy rains on top of the preexisting snow pack. These "rain-on-snow" events result in rapid

snowmelt and produce an abrupt increase over the usual low winter base flows in the river (Box et al. in press, p. 9). The basin is also subject to intense local storms that are characteristic of mountainous areas. These summer thunderstorms are of short duration, but they can cause significant rill erosion, mass wasting (downslope movement of rock and soil under the influence of gravity), and transport of colluvium and mine waste from steep slopes as turbid water or debris flows.

## **Winds**

The most common wind patterns in the basin are typical of the mountain valley drainage phenomena. The winds flow parallel to the axis of the valley—typically flowing gently down the valley (from east to west) at night and in the early morning, as a result of the higher elevations cooling faster than the lower elevations, and then reversing direction in late morning as the sun warms the land, and the warm air begins to flow up the valley (TerraGraphics 1990). This is almost a daily pattern if there are clear night skies and no overriding regional weather patterns. Temperature inversions frequently occur at night and in the early morning before the valley warms up. However, during late summer, the area can experience strong (as much as 70 miles per hour [113 km/hour]) dry winds. Such winds seriously exacerbated the spread of the large forest fires experienced in 1910 and 1967 (Pyne 2001).

The winds on Lake Coeur d'Alene are less predictable, with the most common patterns being from either the north or the south along the axis of the lake (URS Greiner, Inc. and CH2M Hill 2001b, p. 3-3).

## **Mining-Related Wastes**

An estimated 109 million metric tons (121 million U.S. tons) of contaminated mine tailings were produced by the mines and mills that operated in the Coeur d'Alene River basin (Long 1998). Most of these tailings—56 million metric tons (62 million U.S. tons)—were discharged to the basin's streams. These discharged wastes contained an estimated 800,000 metric tons (880,000 U.S. tons) of lead and more than 650,000 metric tons (720,000 U.S. tons) of zinc. These and other mining wastes that were discharged to the river systems intermixed with uncontaminated soils and sediments to produce what the U.S. Environmental Protection Agency (EPA) estimates to be more than 91 million metric tons (100 million U.S. tons) of contaminated materials (EPA 2002, p. 2-1). Another 53 million metric tons (58 million U.S. tons) of wastes containing 350,000 metric tons (386,000 U.S. tons) of lead and at least 650,000 metric tons (717,000 U.S. tons) of zinc "were stockpiled along the floodplain of the Coeur d'Alene River,

placed in one of several tailings impoundments, or used as stope fill” (Long 1998).

Four basic types of wastes were discharged in the basin. The first is “waste rock,” which is relatively unmineralized rock that is removed in uncovering the ore veins. This waste, most of which was dumped at the mine mouth, is relatively uncontaminated. The second type consists of the “jig tailings” disposed in the early mining era. These are generally coarse<sup>1</sup> materials with relatively high metal content. They were commonly dumped into the basin streams or in waste piles near the ore-processing facilities. The third type of waste consists of “flotation tailings,” left over from the flotation method for processing ores, which came into use in the early 1900s. These tailings are much finer than the jig tailings and contain lower concentrations of most metals. The flotation tailings also were commonly dumped into the streams. The fourth type of waste includes a wide variety of wastes discharged to the air, water, and land by the smelters and other mining operations. The smelting facilities were located in the middle basin in the 21-square-mile (54 km<sup>2</sup>) area addressed in operable units 1 and 2 (OU-1 and OU-2) of the Superfund site. These wastes can have a wide range of physical and chemical characteristics.

Metals in these wastes are the contaminants of greatest concern, particularly compounds of lead, arsenic, and zinc. The risks that these contaminants pose to human health and the environment depend not only on their concentration and the exposure to them but also on their chemical form or speciation. Some compounds are more biologically available and, therefore, pose higher risks than others.

## Chemical Transformations and Toxic Effects

Metals in the environment exist in a variety of chemical forms or “species.” For instance, zinc, a metal of primary concern in the Coeur d’Alene River basin because of its toxicity to aquatic ecosystems, can exist in its native mineral form (largely as sphalerite, or zinc sulfide [ZnS], also known as zincblende or zinc ore), in other mineral forms often altered from sphalerite (such as smithsonite, or zinc carbonate [ZnCO<sub>3</sub>], which is also a zinc ore), in reduced sediments (as authigenic ZnS),<sup>2</sup> in solution in a com-

---

<sup>1</sup>Box et al. (in press) described the size ranges of jig tailing grain sizes from eight impoundments of jig tailings in the Prichard and Beaver Creek drainages as follows: >8 millimeter (mm), 16%; 4-8 mm, 9%; 2-4 mm, 11%; 1-2 mm, 12%; 0.5-1.0 mm, 10%; 0.25-0.5 mm, 15%; 0.125-0.25 mm, 13%; 0.063-0.125 mm, 8%; and <0.063 mm, 6%. Tailings from the flotation process are typically 80% by weight finer than 0.25 mm.

<sup>2</sup>Authigenic ZnS can be formed when Zn<sup>2+</sup> interacts with hydrogen sulfide (H<sub>2</sub>S) that is produced during sulfate reduction in sediments containing organic matter. Authigenic ZnS forms in oxygen-depleted wetlands, marshy areas, and lake sediments of the Coeur d’Alene basin.

pletely dissociated ionic state ( $\text{Zn}^{2+}$ ), or in a dissolved form complexed with other inorganic or organic solutes. Speciation of metals is driven by a variety of biotic and abiotic processes. Solid compounds can dissolve in water to the ionic form. This process occurs rapidly for solids that are soluble but slowly for those that are insoluble.

Weathering (commonly oxidation) can convert relatively insoluble forms of minerals into more readily soluble ones (such as the conversion of sphalerite to smithsonite or hydrozincite  $[\text{Zn}_5(\text{CO}_3)_2(\text{OH})_6]$ ). Weathering occurs on surfaces, so more rapidly in minerals with increased surface area (for example, in finely ground rock compared with large pieces). Once in solution, ionic zinc is a reactive molecule and undergoes a variety of interactions with other ions or with dissolved organic matter. These interactions affect the solubility of the compound. For example, the formation of authigenic  $\text{ZnS}$  will remove zinc from solution while zinc complexed to dissolved organic matter likely will remain in solution. These are dynamic and reversible processes, driven by a multitude of ever-changing biologic and environmental variables (pH, oxic state, temperature, and moisture). Thus, the potentially toxic metals exist as multiple chemical species in the environment whose behavior and toxicity can be markedly different.

Several groups (EPA 2003, 2004a; NRC 2003) recently have pointed out the importance of speciation in making metals bioavailable (in a form capable of exerting toxicological effects). To exert toxicity, a metal must be present as a species that is capable of interacting with a target site, the target site must be accessible to the chemical, and the target site must be available to interact with the metal. To illustrate, zinc exerts toxicity to fish by interacting with receptors on their gills. It is expected that zinc must be in its dissolved state to interact with these sites. If zinc is adsorbed to, for example, ferric oxyhydroxide,<sup>3</sup> it will not be available to interact with the sites of toxic action. Accessibility (or exposure) of the sites of toxic action is not a constraint, because gills are in intimate contact with the water and have an extremely high surface area to facilitate oxygen exchange between the water and the fish's blood. However, these sites may already be occupied by other nontoxic metals with similar chemical properties, particularly calcium and magnesium, the commonly dissolved cations that constitute the "hardness" of water. Because these other cations also can react with the receptor site, the toxicity of zinc depends on the concentrations of these competitive species. Thus, the toxicity of zinc to fish is also highly dependent on the hardness of the water.

In humans, the same types of interactions are important, but the organism and the environment (terrestrial instead of aquatic) are fundamentally

---

<sup>3</sup>Also referred to as hydrous ferric oxide.

different. Here, lead is the metal of primary concern, and the factors limiting the expression of toxicity are conversion of the metal to its ionic state and uptake of the metal from the gut to the bloodstream. Except in exposures from ingestion of water, lead is present as a solid upon ingestion or inhalation. Similar to zinc, the ongoing process of oxidation/weathering in the environment can convert lead sulfide (PbS), which is relatively insoluble, to a variety of more soluble species such as lead carbonate ( $\text{PbCO}_3$ ). This process is accelerated by large surface-areas-to-volume ratios (small particle sizes) and favorable environmental conditions.

Thus, in similar environmental conditions, finely ground flotation tailings may present a greater risk to humans and waterfowl than coarser jig tailings, even though flotation tailings contain a lower concentration of lead in them. The fine tailings have a much larger surface area per pound of material than the coarser materials, providing much more opportunity for the PbS in the tailings to be oxidized to a form that is more biologically available.<sup>4</sup>

For humans, there are several other reasons why the finer particles may present more risk. They are more likely to cling to children's skin, which makes them more likely to be ingested when children put their hands in their mouths or touch food without washing their hands. They are more likely to cling to children's clothes and shoes, which makes them more likely to be tracked into the house where they contribute to continuing exposure through house dust (see discussion in Chapters 5 and 6 of this report). They are also more likely to be picked up by breezes and become atmospheric dust, making them more likely to be inhaled by children playing outside or be carried into children's homes (particularly, as indicated above, in older homes that have higher air infiltration rates).

An additional reason why the finer particles may present increased risk to waterfowl is that floods are more likely to carry the finer materials into the wetlands and lateral lakes in the lower basin. The coarser metal-enriched sediments tend to settle out of the flood waters near the river channel, forming the natural levees that border the river.

Within the organism, the different lead-bearing compounds will have various tendencies to dissociate into ionic lead ( $\text{Pb}^{2+}$ ). For example, PbS is poorly soluble, but other lead species such as  $\text{PbCO}_3$  are substantially more

---

<sup>4</sup>However, there are a number of reasons why these opportunities may not be realized. The fine tailings and coarse tailings are often found in different environmental conditions, particularly with respect to the availability of oxygen. They are often deposited in different locations, and the density of the deposits of the fine tailings makes them less permeable, and therefore slows the infusion of oxygen. Under oxidizing conditions, fine tailings may be leached of metal content more quickly than coarse particles. Of course, dissolved metals also may reprecipitate in the environment through biotic or abiotic mechanisms as solid chemical species, with a wide range of potential solubility.

soluble. After ingestion of lead-contaminated soils, the uptake of any soluble lead will also be modified by the presence of food in an individual's stomach, with absorption of lead declining in the presence of food. Once in the bloodstream, lead is available to exert a toxic effect (see Chapter 5 for further discussion).

All these factors that affect the toxicity of the wastes discharged into the basin can be affected by environmental factors. Jig tailings initially dumped into the river usually contained relatively insoluble metal compounds that exhibit limited toxicity. However, as these materials are exposed to air and water, the chemical nature of the compounds can change, increasing their bioavailability and their potential toxicity. In addition, the mixture of metals present may also change, so that the modifying effect of such mixtures on the toxicity of individual metals may also change (La Point et al. 1984).

In some cases, the indirect effects of the contamination may be a major factor. For instance, it is not only the direct toxic effect of these contaminants to fish that is of concern, but also their effect on the stream benthic organisms. These organisms are the primary source of food for the fish and fill a number of other food-web roles including herbivorous shredders, scrapers that consume attached algae and biofilm ("aufwuchs"), filterers and gatherers that consume detritus and suspended phytoplankton, and carnivorous engulgers that consume other invertebrates (Cummins and Klug 1979). They are often highly sensitive to dissolved metals and other contaminants, and in some parts of the basin only a few species (that are metal tolerant) now exist (Stratus Consulting, Inc. 2000).

Furthermore, as indicated above, the presence of contaminants can interact with other environmental factors in a way that either increases or decreases toxic effects. For instance, in addition to being a source of contaminants, the high sediment loads in the Coeur d'Alene River and its tributaries have a variety of biologic and physical effects on aquatic systems. These effects include the destruction of spawning areas, promotion of anoxic conditions, lowering the rate of recruitment into fish and invertebrate populations, inhibition of respiration, and limitation of light (Hynes 1970). These types of changes are very important in assessing the risks that the contaminants pose and what actions need to be taken to support a return of healthy aquatic ecosystems.

Finally, the risks that these contaminants pose depend on the species and segments of the population that are exposed to them (see Box 3-2).

## THE UPPER BASIN

The upper basin, which includes the upper reaches of both forks of the Coeur d'Alene River as well as all the tributaries to these forks, is where

**BOX 3-2 Who's at Risk?**

Metals in the Coeur d'Alene River basin pose risks that vary for different segments of the human population and species of wildlife.

For humans, young children are much more susceptible to the effects of lead poisoning than adults because lead affects the neurological development that occurs during a child's early years. Young children also may have higher exposure as a result of their tendency to play on lawns or on floors, and other surfaces that may be contaminated.

For aquatic ecosystems, some varieties of fish and benthic organisms are more sensitive than others. For example, rainbow trout are particularly susceptible to dissolved metals, including zinc and cadmium (Davies and others 1976). There are numerous reports of the sensitivity of trout in the Coeur d'Alene River to dissolved metals. Farag et al. (1998) demonstrated that trout and other biota in the Coeur d'Alene system contain elevated concentrations of metals, and, in another study, that the growth and survival of cutthroat trout were reduced when they were fed macroinvertebrates from the South Fork (Farag et al. 1999). A study on trout sensitivity to metals in Coeur d'Alene River waters indicated that trout would spend as little as 3% of the time in contaminated water when given a choice of movement and that the fish avoided zinc concentrations as low as 28 µg/L (Woodward et al. 1997). Studies also indicate that dietary exposure to zinc and cadmium affects the early developmental stages of invertebrates and fish (Farag et al. 1998). Sculpin are another fish species with high sensitivity to metals. Fish population assessments conducted in the Coeur d'Alene River basin documented that these species were absent from metal-contaminated stretches of the river where they otherwise would be expected to be found, and they were more responsive than trout to environmental contamination by metals (Maret and MacCoy 2002). Sculpin are bottom-dwelling organisms that primarily feed on aquatic invertebrates. Among the aspects of their life history that make them useful as indicators of metal contamination are a small home range, inability to move during episodic events of high metal concentrations, a close association with sediments, their propensity to lay and incubate eggs in their range, and their failure to migrate to uncontaminated reaches to spawn (Dillon and Mebane 2002; Maret and MacCoy 2002).

Among waterfowl, tundra swans are particularly susceptible because of their migratory and eating habits. Most swans in the Coeur d'Alene River basin are either en route to their northern breeding grounds in the spring or heading south during wintering periods. They feed primarily on tubers and roots of aquatic plants that grow at shallow depths in lakes and wetlands in the lower basin. In the process of searching for and consuming these foods, they ingest significant amounts of sediment, putting them at particular risk from the lead these sediments contain.

much of the early mining occurred. The major tributaries are Canyon Creek and Ninemile Creek where the first silver and lead mines in the region were located. During the mining era, at least 21 mines and mining complexes operated along Canyon Creek, and at least nine operated along Ninemile Creek (URS Greiner, Inc. and CH2M Hill 2001c, p. 2-4; URS Greiner, Inc. and CH2M Hill 2001d, p. 2-4).

There is still one active mine in the upper basin, the Lucky Friday Mine, located slightly east of Mullan. This is an underground mine with an associated flotation mill, producing silver, lead, zinc, and a small amount of gold. Ore is processed at a rate of about 1,000 metric tons (1,100 U.S. tons) per day, and the workings are backfilled with cemented tailings (Hecla 2004). The ore concentrates are shipped to a smelter in British Columbia. The Lucky Friday complex employs about 100 people, although employment is likely to increase as a result of the company's recent decision to double its capacity by developing the Gold Hunter deposit, which lies about a mile northwest of the existing Lucky Friday workings (Hecla 2004).

### Human Community

Although large communities of miners formerly lived in the upper basin valleys, currently there are only a few small settlements and scattered housing units in the tributary valleys. Most houses are quite old, and some lack basic water and sewage services. There are two small incorporated communities in the upper basin, Mullan and Wallace, both located on the South Fork of the Coeur d'Alene River. Table 3-1 shows selected demographic characteristics for these communities compared with the state of Idaho and the United States.

The populations of these communities, which decreased significantly during the 1980s after the mills and many of the mines in the basin closed, are somewhat older and poorer than is typical for Idaho. Wallace, in particular, has a high poverty rate. The housing stock is very old, with more than 80% of the housing units built before 1960, and the number of vacant units is very high, as would be expected in communities losing significant

TABLE 3-1 Demographic Characteristics of Upper Basin Communities

Demographic	U.S.	Idaho	Mullan	Wallace
Population			840	960
Median age (years)	35.3	33.2	41.4	40.6
Older than 65 (% population)	12.4	11.3	16.8	16.0
Median household income (\$ thousands)	42.0	37.6	30.4	22.1
Below poverty level (% individuals)	12.4	11.8	12.1	20.1
Unemployment rate	5.8	5.8	11.6	11.5
% with bachelor's degree	24.4	21.7	10.8	17.2
% moved from out of state since 1995	8.4	15.3	14.8	21.8
% of owner-occupied units occupied by the same family for >30 years	9.7	6.9	22.7	14.8
Vacant housing units (%)	9.0	11.0	19.5	27.3
Houses older than 40 years (%)	35.0	27.7	78.6	93.3

SOURCE: U.S. Census 2004.

numbers of residents. A relatively high percentage of the residents in these communities has lived in the same house for more than 30 years. These are the households that stayed behind in spite of the economic problems that affected the basin.

However, there are also new residents moving into these communities. The percentage of residents who moved into these communities between 1995 and 2000 from out of state was as high as or higher than the average for Idaho and much higher than the average for the United States.

## Geology and Fluvial Geomorphology

### Bedrock Geology

This portion of the Rocky Mountains is a region of high mountain masses with steep valleys and no individually distinct mountain ranges. The bedrock of the basin (and host rock for the ore veins) is composed of argillite, slate, quartzite, and lesser amounts of impure, metamorphosed dolomite. These rocks are geologically grouped into the Belt Series, a sequence of indurated and mildly metamorphosed sedimentary rocks in northern Idaho, western Montana, and parts of British Columbia and Washington. Belt Group rocks were originally clay, silt, and fine sand layers deposited along the continental margins of a Precambrian sea between 1,500 and 1,400 million years ago (Winston 2000). The sediment layers have been indurated, folded, and faulted. In the Coeur d'Alene mining district, the rocks are intensely fractured and veined with minerals. Folding has so crumpled the layers that most dip at angles steeper than 45°.

The zone of intense shearing and faulting is along a regional structure known as the Lewis and Clark line, extending westward from central Montana to Spokane. Along this line, stream valleys such as the South Fork of the Coeur d'Alene River are guided by the zones of more easily eroded fractured rock.

The myriad fault and fracture zones along the Lewis and Clark line also contain the mineralized zones of the Coeur d'Alene mining district. The ore deposits are in veins composed primarily of quartz and siderite ( $\text{FeCO}_3$ ). The ore veins are separated into two major types by mineralogy: (1) lead- and zinc-rich veins have argentiferous galena ( $\text{PbS}$ ) and sphalerite ( $\text{ZnS}$ ), and (2) silver-rich veins having argentiferous tetrahedrite  $[(\text{Cu}, \text{Ag})_{10}(\text{Fe}, \text{Zn})_2(\text{As}, \text{Sb})_4\text{S}_{13}]$  and minor amounts of galena and sphalerite (Balistrieri et al. 2002a). Pyrite ( $\text{FeS}_2$ ) is ubiquitous but variable in abundance in the ore veins. Most veins contain small amounts of chalcopyrite ( $\text{CuFeS}_2$ ) and minor amounts of other minerals including arsenopyrite ( $\text{FeAsS}$ ) and pyrrhotite ( $\text{Fe}_{1-x}\text{S}$ ). The veins generally range from a few millimeters to 3 m in thickness, but some are up to 15 m thick (Hobbs and Fryklund 1968; URS

Greiner and CH2M-Hill 2001b, p. 3-15). In the early development of the district, oxidized ore mined from the Bunker Hill, Sullivan, Last Chance, Morning, and Standard-Mammoth deposits contained significant amounts of cerussite ( $\text{PbCO}_3$ ), and locally massicot (earthy yellow  $\text{PbO}$ ), and natural litharge (red  $\text{PbO}$ ). Anglesite ( $\text{PbSO}_4$ ) was notably absent (Ransome and Calkins 1908). Oxidized ore in the upper levels of these ore bodies was mined for the  $\text{PbCO}_3$  and wire silver. However, by 1904 only one mine had a large deposit of carbonate ore remaining. The lower limit of oxidized ore in the district was very irregular, with carbonate noted in vugs and fractures to several hundred feet, but at the Bunker Hill Mine, unoxidized galena was discovered at the surface (Ransome and Calkins 1908, pp. 97, 133). The existence of  $\text{PbCO}_3$  ore is important because it has greater bioavailability than sulfide ore and probably is present in the early jig tailings.

Beyond the main ore bodies, higher concentrations of sulfide minerals occur in proximity to an igneous stock and along the major faults. Zones of disseminated sulfide minerals extend tens to hundreds of meters outside of veins at the Lucky Friday Mine (White 1998). Within the stratified rocks, only the argillite and quartzite of the Pritchard Formation contain appreciable disseminated sulfide in the lower part of the formation, occurring as fine  $\text{FeS}_2$  and/or  $\text{Fe}_{1-x}\text{S}$  in the argillite (Hobbs et al. 1965; URS Greiner and CH2M Hill 2001b, p. 3-8).

### Soils and Sediments

The natural hillsides have podzolic forest soils, with 10- to 19-inch- (25- to 50-cm)-thick upper, dark-brown horizons containing 2-5% organic matter. The soils are described as loamy skeletal soil, meaning mixed rock fragments with the soil fines having a clay content of 3-18% with the remainder being silt and sand. Soils are naturally acidic with a pH of 5.6-6.5, and cation exchange capacities of 15-30 milliequivalents (meq)/100 grams (g) in the upper 10 inches (25 cm) (NRCS 2003).

The thickness of soil and loose rock on hill slopes is variable. Bedrock exposures are common, but hill slope colluvial hollow and foot slope accumulations up to 10 m (33 feet) thick of mixed rock and fines are common. Differences in soil types and thickness and vegetation are expected between north- and south-facing slopes because of sun exposure and moisture retention.

The hillsides and hollows adjacent to former mining operations are covered with piles of waste rock and jig tailings. Waste rock dumps are uncrushed rock materials containing little metal removed during the active mining phase and placed just outside the mine openings. Jig tailings are the relatively coarse-grained materials left over from the inefficient jiggling process that was used in the late 1800s and early 1900s to concentrate the ore. This process left tailings with relatively high metal concentrations. Some of

the jig tailings were deposited in the waste rock dumps, some were placed in other repositories, but most, at least initially, were dumped into the upper basin tributaries to wash downstream (see Chapter 2). In the late 1960s, the dumping of mine tailings into surface water was stopped and tailings were collected in repositories or tailings ponds. The largest upper basin tailings pond is the 66-acre (27-hectare) Hecla-Star tailings pond at the bottom of Canyon Creek containing about 2.1 million cubic yards (1.6 million m<sup>3</sup>) of material (URS Greiner, Inc. and CH2M Hill 2001c, p. 2-7; URS Greiner, Inc. and CH2M Hill 2001e, Appendix J, Table A-5).

### Stream Channels

The stream segments in the upper basin have relatively steep gradients (>60 feet/mile [11 m/km]) and flow through narrow valleys in canyons with steep walls. Before the beginning of mining, the streams would have been typical mountain streams characterized by step-pool and plain-bed channels (Montgomery and Buffington 1997) lined predominantly with bedrock or cobble-boulder beds. Boulders, large logs, and log jams likely gave some degree of channel stability, providing hydraulic steps and pools and some sediment storage. The upper basin streams typically had little or no floodplain along their length, although some of the creeks did have discontinuous forested floodplains up to a few hundred meters (about 1,000 feet) wide (see Figure 3-3).

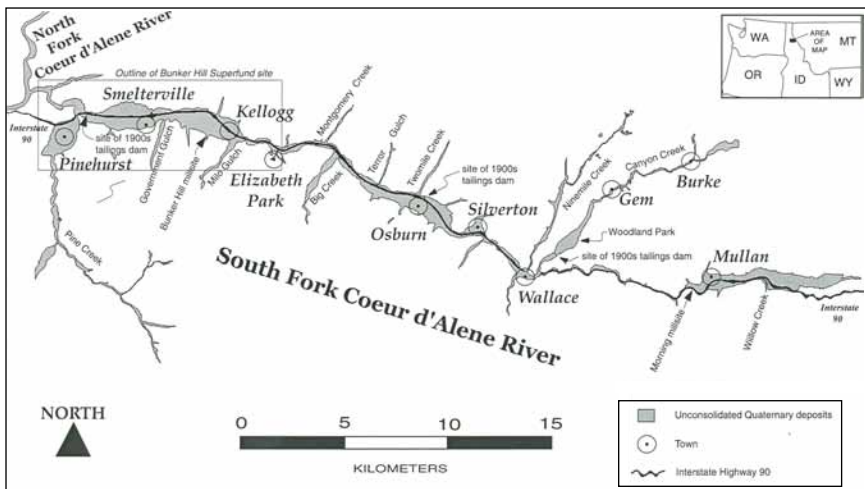


FIGURE 3-3 Upper and middle reaches of the Coeur d'Alene River showing valley fills and towns. SOURCE: Box et al. 1999.

During the early mining era massive amounts of relatively coarse jig tailings were dumped into these channels, causing them to aggrade. Since then, many reaches of these streams have been artificially channelized, and remediation projects have excavated some of the contaminated tailings and placed them in unlined and uncapped repositories out of the active channel ways (Harvey 2000; URS Greiner, Inc. and CH2M Hill 2001c, p. 3-4 to 3-14). In the more heavily mined tributaries such as Canyon and Ninemile Creek, the alluvial flats are underlain by 20-40 feet of alluvium (URS Greiner, Inc. and CH2M Hill 2001c, Fig. 2.1-1; Houck and Mink 1994, Fig. 10). The surficial layer of jig tailings in lower Canyon Creek is 2-4 feet thick (Houck and Mink 1994, p. 5).

These streams are still transferring metal-enriched sediments into the Coeur d'Alene River. Canyon Creek, for instance, is estimated to be discharging an average of 2,200 metric tons (about 2,400 U.S. tons) (equivalent to 1,360 m<sup>3</sup> or 1,780 cubic yards) of sediment a year to the South Fork at Wallace (URS Greiner, Inc. and CH2M Hill 2001c, Table 3.2-1). Most of this sediment is likely to be composed of native sediments mixed with tailings heavily contaminated with lead and other metals.

## Hydrology

### Surface Water

The upper basin streams display flow variations typical for mountain streams. Canyon Creek, for instance, has a base flow discharge estimated to be 10-15 cubic feet per second (cfs) (280-425 L/s), and the ten-year flood is estimated to have a peak flow about 100 times this base flow. The minimum discharge is less than 0.5 cfs (14 L/s) (URS Greiner, Inc. and CH2M Hill 2001c, p. 2-16). EPA's study of the upper basin tributaries (for example, Canyon and Ninemile Creeks) found that high waters overflow the banks an average of once every 1.5 years (URS Greiner, Inc. and CH2M Hill 2001c, p. 2-18; URS Greiner, Inc. and CH2M Hill 2001d, p. 2-14). However, a more recent study by the U.S. Geological Survey (USGS) finds that "the ratio of runoff to precipitation has increased, especially since the early 1960s. Some tributary streams that once ran bank-full or more about twice in 3 years now run bank-full 5 or 6 times a year. As a result, rates of erosion, sediment transport, and deposition also have increased" (Bookstrom et al. 2004a).

High water flow events carry significant amounts of sediment that are derived from erodable materials in the river bed, river banks, and floodplain (Box et al. in press). In contrast, low flows carry the highest concentrations of dissolved contaminants. The low flows are fed entirely by

groundwater discharges, and the high contamination levels result from the percolation of these waters through tailings deposits.

## Groundwater

In the upper basin, there are basically two types of groundwater aquifers. The first is the bedrock groundwater system, which flows through fractures in the relatively impervious bedrock. The recharge to this system occurs primarily from rainfall and snowmelt in the mountains and from stream flow and riparian aquifers losing water to bedrock in the lower reaches of streams. The underground mining operations effectively created a system of drains tapping the fracture systems and, as a result, much of the bedrock aquifer groundwater discharges into old mining operations and appears as "adit flow." The second type of aquifer is the shallow aquifer existing in the alluvium, tailings, and waste rock along the valley floor. The recharge to this system comes from seepage from the stream and discharges from the bedrock aquifer as well as from precipitation and snow melt. These surface aquifers are the source of the late summer "base flows" in the streams.

## Dissolved Metals

Processes controlling the metal loading of groundwater are not known with certainty. Groundwater flow rate, water acidity, presence of carbonate minerals, fluctuating water tables, and chemical processes in the unsaturated zone are important factors that contribute to the high variability of dissolved metals in the groundwater.

The USGS sampled water draining from adits and seeping from beneath tailing piles for both total and dissolved metals (Balistrieri et al. 1998, 2002a). The investigators reported the following mean values for dissolved zinc concentrations: adits (other than the Kellogg Tunnel), 5.8 mg/L; tailings-seeps, 66 mg/L; groundwaters, 38 mg/L; and the Coeur d'Alene River, 3.4 mg/L (Balistrieri et al. 2002a). The zinc concentration is highly dependent on the pH of the water, and carbonate minerals in the soil can reduce acidity (Balistrieri et al. 2002b).

Discharges from the bedrock aquifer contain relatively low concentrations of dissolved metals. Even the adit drainages contribute few dissolved metals. Most adit drainage waters are not acidic (pH = 6.5-7.8) and, therefore, have limited capacity to dissolve metals. The few adit drainages in the upper basin that have significant concentrations of dissolved metals (Success, zinc at 50 mg/L; Gem, zinc at 16 mg/L) have low flow rates (0.02 and 0.2 cfs [0.5 and 5 L/s], respectively), which yield relatively small loads

(Balistrieri et al. 1998). The average zinc loading from all of the adits in the major upper basin mining areas (Canyon Creek, Ninemile Creek, the upper reaches of the South Fork, and Pine Creek) is about 71 pounds (lbs) per day (URS Greiner, Inc. and CH2M Hill 2001c, p. 4-106; 2001d, p. 4-77; 2001f, p. 4-68; 2001g, p. 4-44). This is about 2% of the total dissolved zinc load at the mouth of the Coeur d'Alene River.

More significant contributions of dissolved metals come from discharges from the shallow aquifers that exist in the alluvium, waste rock, and tailings deposited on the sides and bottoms of the stream valleys. Zinc concentrations in the seepage from many of these areas are in the 10-20 mg/L range but can be substantially higher (for example, the zinc concentration from a seep in the Ninemile Creek drainage was 350 mg/L) (URS Greiner, Inc. and CH2M Hill 2001d, p. 4-77). This suggests the ease of oxidation of ZnS under these conditions. However, the highest concentrations were generally associated with low flow rates. Measurements of seeps draining abandoned tailings piles have shown high concentrations of dissolved metals in Ninemile Creek and Canyon Creek (Balistrieri et al. 1998; URS Greiner, Inc. and CH2M Hill 2001c, p. 4-106; URS Greiner, Inc. and CH2M Hill 2001d, p. 4-77). Because the flow rates were low, these seeps contributed relatively little to the dissolved zinc load (an average of 11.2 lbs per day for the two seeps measured in Canyon Creek and 11.7 lbs per day for the three seeps measured in Ninemile Creek) (URS Greiner, Inc. and CH2M Hill 2001c, p. 4-106; 2001d, p. 4-77). The total contribution of these tailings and waste rock piles, however, cannot be determined from the available data because so few measurements were made, and because much of the flow through these deposits probably enters the underlying aquifer directly rather than appearing on the surface as seeps.

The other shallow aquifer discharges result from seepage of surface water into, and subsequently out of, the valley floor aquifers. A study of one of these aquifer systems showed seepage into and out of a 3.3 mile (5.3 km) stretch of alluvium underlying the downstream portion of Canyon Creek occurring at a rate of 3-5 cfs (85-140 L/s), with the return seepage flows high in dissolved zinc (650-30,000 µg/L) and other solutes (Houck and Mink 1994; Barton 2002). The estimated amount of dissolved zinc entering the stream from shallow aquifer discharges along this 3.3 mile stream segment was 150 lbs (68 kg) per day. This average load value is based on measurements during the low-flow months of September and October 1999. The contribution may be significantly higher at most other times of year when groundwater elevations are higher.

In total, however, EPA estimates that the upper basin streams contribute less than one-third of the total dissolved zinc loading measured to the Coeur d'Alene River (URS Greiner, Inc. and CH2M Hill 2001a, Figs. 5.3.5-8,9,10). Canyon Creek makes the largest contribution, 15% of the total,

with Ninemile Creek next at 7%. The South Fork above Wallace and all the other tributaries contribute 2% or less (see Figure 3-4 for details on zinc loadings during water year 1999-2001).

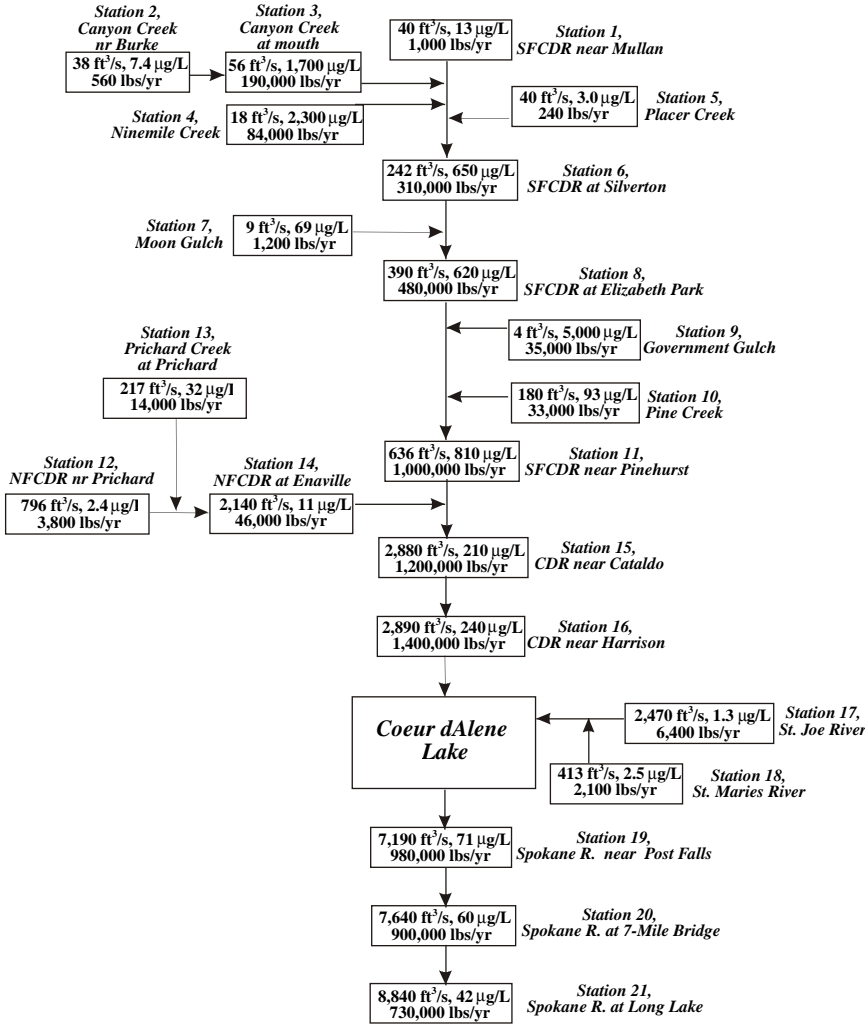


FIGURE 3-4 Sources of zinc in the Coeur d'Alene River in water years 1999-2001. Boxes for each location (station) present mean annual stream discharge, mean flow-weighted concentration, and mean annual load of total zinc. SOURCE: Clark 2003.

### Ecologic Community

Before the beginning of mining, the hills and valleys of the Coeur d'Alene River basin were heavily forested. The hillsides were covered with a rich mixed-conifer forest of Douglas fir, grand fir, ponderosa pine, western larch, and western white pine, and the valleys were forested with cedar and lodgepole pine, cottonwood, and other riparian trees. Red cedar boles and large logs that fell into streams provided pool habitat for fish, sediment storage, and some degree of channel stability (Harvey 2002, p. 8).

Much of the original timber was cut down during the mining era for building construction, mine-shaft support, and fuel, or it was destroyed by fires such as that of 1910, which burned much of the basin above Kellogg (Hart and Nelson 1984; Pyne 2001). Over the past half century or longer, however, the forests have been allowed, and in some cases actively encouraged, to regenerate, and as a result the natural vegetative cover on the valley slopes is returning. The basin contains National Forest, Bureau of Land Management, state of Idaho, and private lands that can be leased out for timbering. For instance, there has been extensive timbering along the North Fork of the Coeur d'Alene River. The timbering often results in increased runoff and sediment (Idaho Panhandle National Forests, 1987, 1998, 2002; CBFWA 2001).

Although the return of the forests to most of the upper basin area has reestablished the habitat needed by the wildlife species that naturally inhabit such areas, the foresting operations and construction and maintenance of the logging roads continue to reduce the value of this habitat. Much of the basin has a very high logging-road density (greater than 4.7 linear miles of road per square mile [2.8 km/km<sup>2</sup>]) (CBFWA 2001, p. 62).

### Aquatic Habitat

Upstream of the areas affected by mining operations, the upper basin streams are relatively healthy. EPA has found that the fish, such as cut-throat trout and sculpin, and the benthic communities are diverse and healthy (CH2M-Hill and URS Corp. 2001). Abundant trout populations can even be found in some upper basin river segments affected by mining. For instance, the South Fork of the Coeur d'Alene River above Wallace has an average dissolved zinc concentration of approximately 190 µg/L, about five times the ambient water-quality criteria (AWQC), but the trout density is quite high, similar to that in morphologically similar reaches in the St. Regis River, which has not experienced serious mining impacts (Stratus Consulting, Inc. 2000). However, sculpin, which would be expected to be abundant in the South Fork and its tributaries, do not fare so well. A recent

study (Maret and MacCoy 2002) demonstrated that sculpin were absent from stretches of the river where zinc concentrations exceeded the AWQC.

The quality of the aquatic and riparian habitat along many of the upper basin streams affected by mining remains severely degraded. Efforts to reestablish vegetation in the tailings deposits along the upper basin stream channels usually have been relatively unsuccessful (URS Greiner, Inc. and CH2M Hill 2001c, p. 1-1). These problems, combined with high concentrations of dissolved metal, result in the streams showing a substantial reduction (and in some segments elimination) of native fish species and a decline in the diversity and abundance of benthic macroinvertebrates (URS Greiner, Inc. and CH2M Hill 2001b, p. 3-51).

### THE MIDDLE BASIN

Before the mining era, the river segments in the middle basin would have had the characteristics of braided streams, with their beds predominantly composed of gravel and having a relatively shallow depth (except during flooding). The floodplains were described as heavily forested or marshy (Box et al. 1999, p. 5).

Most of the large mining communities and large ore-processing facilities were located along the middle reach of the South Fork of the Coeur d'Alene River. These communities, with their housing, mine-processing facilities, and transportation facilities, are built on top of and, in the case of the railroad and interstate highway embankments, largely out of the vast amounts of mine tailings deposited in this reach. The original Bunker Hill Superfund site lies in the middle of this reach. This site, commonly called "the box," is a rectangular area that runs from Kellogg on the east to Pinehurst on the west and contains the Bunker Hill smelter and all the other facilities, residences, and land within its 21-square-mile (54-km<sup>2</sup>) area. The site is composed of two OUs designated OU-1 (for populated areas) and OU-2 (for the rural and former industrial areas) and was the focus of cleanup efforts begun in the early 1990s. Although EPA has excluded the box from consideration in its plans for OU-3, it continues to be a major source of dissolved metals in the lower Coeur d'Alene River.

There are currently two active mines in the middle basin. One is the Galena Mine located 2 miles west of Wallace, and the second is the Bunker Hill Mine located in Kellogg. In addition, a group of investors is reported to be exploring the possibility of reopening the Sunshine Mine located near Kellogg<sup>5</sup> (Sterling Mining Company 2004).

---

<sup>5</sup>The Sunshine Mine was the richest silver mine in American history with more than 360 million ounces of production over the past century. It was also the site of the 1972 mine-fire disaster that killed 91 miners (USMRA 2004).

The Silver Valley/Galena Mine is located southwest of Silverton in the valley of Lake Creek. Silver and some copper are recovered by a flotation mill, producing a silver-rich concentrate, which is sold to third-party smelters in Canada. Flotation tailings are separated into coarse and fine fractions at the mill, and the coarse tailings pumped back into the mines to use as backfill. The fine fraction slurry is piped down Lake Creek to the South Fork valley and then to the 60-acre Osburn tailings ponds, situated at the southeast end of the Osburn Flats. The fines are settled in the impoundment and the clarified water decanted and carbon/charcoal filtered before waste water is discharged to the river (EPA 2001). The mine, which produced 165,000 tons of ore and 3.7 million ounces of silver in 2003, employs about 200 people. Development work at the mine is ongoing and production is expected to increase approximately 40% by 2006 (Coeur d'Alene Mines Corporation 2004; Gillerman and Bennett 2004).

The Bunker Hill mine is, at present, a much smaller operation. Its owner reports that he occasionally mines 18-36 metric tons (20-40 U.S. tons) of ore per day and employs nine people (Robert Hopper, Bunker Hill Mine, personal commun., April 14, 2004). If silver or zinc prices were to rise substantially, this mine might be able to return to commercial production, although it faces a number of problems related to the disposal of its mining wastes and adit drainage.

Very little development has occurred along the North Fork. Although several mining operations took place in the tributaries of the North Fork, the only settlements are Prichard at the very top of the North Fork watershed and Enaville at the junction with the South Fork. The main activity in the North Fork basin is lumbering. The dense logging roads and forestry operations are a major source of erosion and high sediment loads in the North Fork.

### **Human Community**

From a socioeconomic standpoint, the most significant recent event in the middle basin was the closure of the Bunker Hill smelter in August 1981. The resulting loss of about 2,100 jobs caused significant declines in the populations of the basin's communities (Bennett 1994). As indicated in Table 3-2, the middle basin communities reflect these events, showing many of the same characteristics of the upper basin communities.

These communities are mostly larger than those in the upper basin. The median age of residents is older than for the rest of Idaho and the United States, but, compared with the upper basin communities, the median age is younger and a smaller proportion of the residents have been living in the same house for more than 30 years. Another major difference from the upper basin communities is that a significant portion of these

TABLE 3-2 Demographic Characteristics of Middle Basin Communities

Demographic	U.S.	Idaho	Osburn	Kellogg	Wardner	Smelterville	Pinehurst
Population			1,545	2,395	215	651	1,661
Median age (years)	35.3	33.2	44.6	37.4	41.5	39.4	41.6
Older than 65 (% of population)	12.4	11.3	20.7	18.4	13.0	18.6	19.3
Median household income (\$ thousands)	42.0	37.6	29.9	25.9	25.5	21.9	27.8
Below poverty level (% individuals)	12.4	11.8	11.7	21.8	12.8	22.4	14.8
Unemployment rate (%)	5.8	5.8	8.7	11.6	7.1	14.7	8.4
% with bachelor's degree	24.4	21.7	10.9	10.6	6.6	3.1	7.4
% moved from out of state since 1995	8.4	15.3	11.0	17.8	20.9	15.8	11.7
% of owner occupied units occupied by the same family for >30 years	9.7	6.9	12.8	16.1	23.1	15.7	14.8
Vacant housing units (%)	9.0	11.0	11.1	17.4	20.7	13.2	6.9
Houses older than 40 years (%)	35.0	27.7	52.0	74.0	85.0	61.6	40.7

SOURCE: U.S. Census 2004.

residents—more than 26% in Smelterville—live in mobile homes (U.S. Census 2004).

In terms of structure, the families in these communities are more typical of state and national averages, with 5-8% of the population less than 5 years old, compared with 4-4.5% for the upper basin communities. A significant percentage of the families moved here recently, but average household incomes are low, and poverty rates are high.

### Geology and Fluvial Geomorphology

The bedrock forming the valley walls in the middle basin has the same geological characteristics as that in the upper basin, and a number of major mining operations have taken place along the middle reach of the South Fork. As a result, in several areas, the hill slopes are covered with the same sorts of waste rock and tailings as are found in the upper basin. A major difference in the soil characteristics is found in the hills on the south side of the South Fork from Kellogg to Smelterville where acidic emissions from the Bunker Hill smelter substantially contaminated the soil, preventing the reestablishment of vegetation. The lack of vegetation, in turn, has made the hills subject to sloughing and erosion. Sampling of the soils on the hillsides above east Smelterville found mean concentrations of lead at approximately 9,000 mg/kg (TerraGraphics 2000, p. 6.11), making them a concern for recontamination of the remedial work completed in residential areas of the box.

The major geomorphic differences between the upper basin and the middle basin are in characteristics of the river and the valley floor. Below the confluence with Canyon Creek at Wallace the valley floor widens, the valley fill becomes thicker, and the river slope begins to gradually flatten. The valley fill beneath the floodplain increases in thickness from less than 30 feet (9 m) at Wallace to 80 feet (24 m) at Kellogg to 140 feet (43 m) at Smelterville (Dames and Moore 1991) and is largely comprised of pre-mining depositional sediments (Figure 3-5). However, much of the floodplain is covered with jig-bearing alluvium with an average thickness of approximately 4 feet (1.3 m) (Box et al. 1999).

In its natural state, the river here would have exhibited the characteristics of a braided stream. The widening of the channel and floodplain in the middle basin would have caused a reduction in flood-water depth and velocity, resulting in the deposition of flood-entrained bedload deposits. The main channel would have switched back and forth across the floodplain, building up deposits of sand-to-cobble-sized alluvium (Box et al. 1999, p. 5).

The rate of deposition substantially accelerated after mining began, because tailings were disposed directly into streams. By 1903, tailings depo-

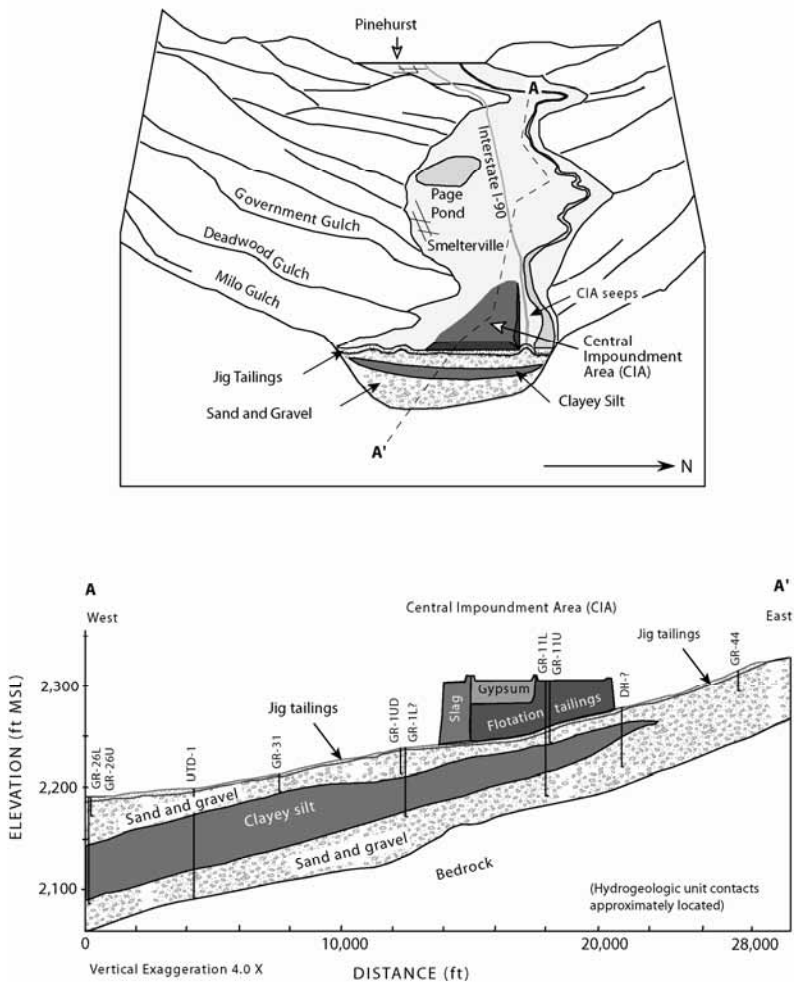


FIGURE 3-5 Diagram looking downvalley and geologic cross section of valley fill of the South Fork of the Coeur d'Alene River valley west of Kellogg showing aquifer units and wells. SOURCE: modified from Dames and Moore 1991.

sition over the broad valley floodplains at Osburn Flats and Smelterville Flats resulted in barren wastes of gray jig tailings 1-2 feet thick through which projected the dead stumps of trees (Box et al. 1999, p. 8; Bookstrom et al. 2001, p. 24).

In addition to the flood deposits, mines and mills operating along the middle reach have deposited substantial volumes of tailings and other wastes

directly on the floodplains or in unlined large repositories. The largest include the central impoundment area (CIA) at Bunker Hill containing 18.5 million m<sup>3</sup> (24.2 million cubic yards) of various wastes, and Page Pond containing 1.6 million m<sup>3</sup> (2.1 million cubic yards) of tailings (URS Greiner, Inc. and CH2M Hill 2001e, Appendix J, Table A-8). The Osburn Flats tailings pond (containing about 2.7 million m<sup>3</sup> [3.5 million cubic yards] of material) currently receives slurried tailings from the active Galena Mill that are settled in the impoundment. A number of other large contaminated sites, ranging in size from 10 to 30 hectares (25 to 75 acres), are associated with the facilities located within the Bunker Hill complex (URS Greiner, Inc. and CH2M Hill 2001g, Table 4.1-2).

The dumping of large amounts of tailings into the stream's tributaries overwhelmed the river's ability to carry these sediment loads downstream. In an effort to address complaints from downstream farmers about their fields being covered with contaminated materials, wood-piling and cribbing dams were constructed in the channel to contain the sediments, but these were rapidly overtopped and later washed out (Box et al. 1999).

However, efforts to "stabilize" the river channel continued. As described in the remedial investigation (RI): "to accommodate the infrastructure, and to make room for storing and disposing of mining wastes in the floodplain, the channel of the South Fork Coeur d'Alene River has been moved, channelized, armored, and otherwise altered, with only a few reaches still resembling a natural river" (URS Greiner, Inc. and CH2M Hill 2001b, p. 2-11). Remediation efforts carried out pursuant to the ROD for OU-2 again moved the river channel to allow about 1.2 million cubic yards (0.91 million m<sup>3</sup>) of mine waste to be removed from the Smelterville Flats area (EPA 2000; EPA 2004b [July 27, 2004]).

The river continues to carry large amounts of sediment downstream. From 1988 through 1998, EPA's contractors estimated that the average annual sediment load passing Pinehurst, downstream of Smelterville, amounted to almost 20,000 metric tons (22,000 U.S. tons), which is equivalent to about 12,000 m<sup>3</sup> (16,000 cubic yards) (URS Greiner, Inc. and CH2M Hill 2001f, p. 3-42). During 1996, a year experiencing a large flood, the load was almost 70,000 metric tons (77,000 U.S. tons). About half of this load was made up of fines (<63 µm diameter) (URS Greiner, Inc. and CH2M Hill 2001f, p. 3-42). These data emphasize the important role of heavy floods in distributing metal-contaminated sediments throughout the system.

By the time the suspended sediments reach the middle basin, the metals in the fines have had ample time to oxidize and thereby become biologically available. USGS investigators used scanning electron microscopy with x-ray detection of elements and leaching studies to characterize the speciation of lead in samples that were collected from the floodplain and the river and

found that iron and manganese oxides were present and appeared to be host phases for lead, which was also present as  $\text{PbCO}_3$  and  $\text{PbSO}_4$ . They concluded that the galena was oxidized within about 6 miles (10 km) of the original deposit (Balistrieri et al. 2002a).

The North Fork of the Coeur d'Alene River joins the South Fork at the bottom of the middle basin. The North Fork drainage basin is 3 times larger than that of the South Fork, so stream flow is usually 2.5-4 times larger from the North Fork. Mining operations were located on the Prichard and Beaver Creek tributaries of the North Fork, but these do not contribute significant mining waste. The concentrations of metals in water and sediment of the North Fork are low, usually below the EPA screening levels (URS Greiner, Inc. and CH2M Hill 2001h, p. 5-4), and the North Fork supports a good fishery for the westslope cutthroat trout (Abbott 2000). Therefore, flow and sediment transport from the North Fork dilute the South Fork metal concentrations below their confluence.

Although extensive logging activity in the basin probably has increased the magnitude of flood flows in the North Fork, at similar flows (4,000 cfs) (113  $\text{m}^3/\text{s}$ ), the South Fork transports 38 times the suspended sediment and 72 times the bedload of the North Fork (Clark and Woods 2001, Figs. 10, 18). However, because the North Fork drains a larger area, it carries more water. For instance, the peak flood flow with a recurrence interval of 2 years on the South Fork is 3,660 cfs (103  $\text{m}^3/\text{s}$ ) carrying 1,203 metric tons per day (1,327 U.S. tons per day) of sediment (including both suspended sediment and bedload). On the North Fork, the flood with a 2-year recurrence interval is almost 4 times larger (15,100 cfs [428  $\text{m}^3/\text{s}$ ]) and carries 5 times the sediment (6,590 metric tons [7,264 U.S. tons] per day) (Clark and Woods 2001, Figs. 10, 18, p. 18, 26; Berenbrock's 2002 estimates of flood recurrence). Data from 1996 (a flood with >50-year recurrence interval) and 1997 (a flood with 3-4 year recurrence interval) show that larger dilutions of metal-rich with metal-poor sediment may occur in large flood events than in the annual snowmelt flood (Box et al. 2005). In the 1996 event, lead concentrations in suspended sediment below the confluence with the North Fork were approximately 42% of the upstream concentrations while in the 1997 event, downstream lead concentrations were 73% of the upstream concentrations (Box et al. 2005).

Base flow of the North Fork is estimated to be 200-250 cfs, compared with 80-100 cfs on the South Fork, so the high concentrations of dissolved zinc that are harmful to aquatic life are diluted by the relatively uncontaminated flows from the North Fork. This dilution should result in concentrations in the main stem base flow water that are 25% to 35% of the concentrations in the South Fork water.

In the 1999-2000 water year, the South Fork delivered about 20% of the total lead load to Lake Coeur d'Alene; the remaining 80% is derived

from erosion along the course of the main stem Coeur d'Alene River below the confluence of the North Fork (Clark 2003, Fig. 12). Of the approximately 850,000 metric tons of mined lead historically lost directly or indirectly to streams, Bookstrom et al. (2001, Table 15) roughly estimate that 24% (200,000  $\pm$  100,000 metric tons) still resides as sediments in the South Fork drainage.

## Hydrology

### Surface Water

Several stream gauging stations in the middle reach of the South Fork provide intermittent data from 1967 to the present. The major stations are at Silverton, downstream from Wallace (which has the longest record, although it was not in service from 1988 through 1997); Elizabeth Park, upstream of Kellogg; and Pinehurst, downstream of Smelterville. At Silverton, the average flow rate was about 250 cfs (7.1 m<sup>3</sup>/s) and the base flow was estimated to be between 50 and 60 cfs (1.4-1.7 m<sup>3</sup>/s) (URS Greiner, Inc. and CH2M Hill 2001f, p. 2-21).

### Flooding

The Coeur d'Alene River frequently experiences significant floods in late spring as a result of snow melt and, less frequently, winter floods as a result of rain-on-snow events (see Figure 3-6). Figure 3-7 shows the estimated frequency of peak flood discharges for Elizabeth Park and Pinehurst. At Elizabeth Park, the spring floods typically flow in the range of 1,000 cfs for several weeks, with peaks of 2,000-3,000 cfs (56-85 m<sup>3</sup>/s). Heavy rainstorms in the spring can produce temporary, sharp runoff peaks on top of this continued snowmelt runoff (Box et al. in press, p. 9). Major spring floods occurred in 1893, 1894, 1917, 1948, 1956, and 1997 (S. E. Box, USGS, unpublished material, 1994, as cited in Bookstrom et al. 1999, p. 18). The largest winter floods resulting from rain-on-snow events occurred in 1933, 1974, and 1996.

These flood flows transport substantial amounts of sediment downstream (Clark and Woods 2001, Figs 10, 18). The threshold for bedload movement in the South Fork at Silverton is about 200 cfs (5.5 m<sup>3</sup>/s), and a spring flow of 2000 cfs (56 m<sup>3</sup>/s) transports 50 metric tons/day (55 U.S. tons/day) of bedload, and more than 300 metric tons/day (330 U.S. tons/day) of suspended sediment (Clark and Woods 2001). Measurements at Pinehurst showed a transport of 250 metric tons/day (275 U.S. tons/day) of bedload, at 1,830 cfs (52 m<sup>3</sup>/s) and 1,500 metric tons/day (more than 1,600 U.S. tons/day) of suspended sediment in flows of 3,600 cfs (about 100 m<sup>3</sup>/s).

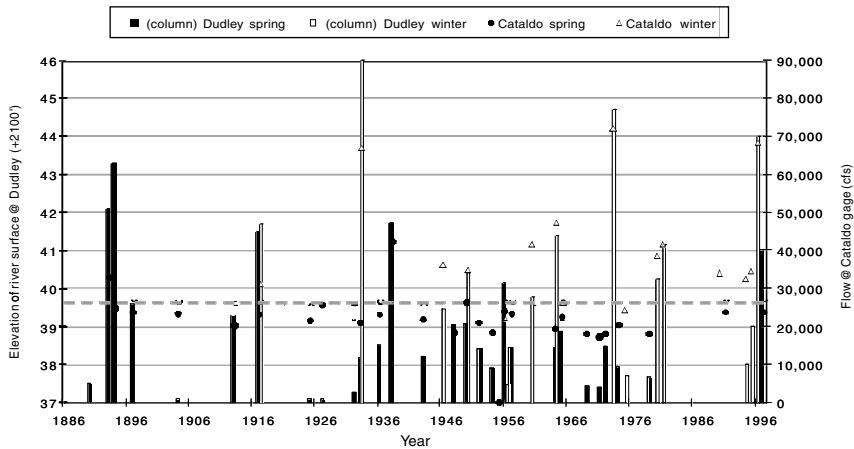
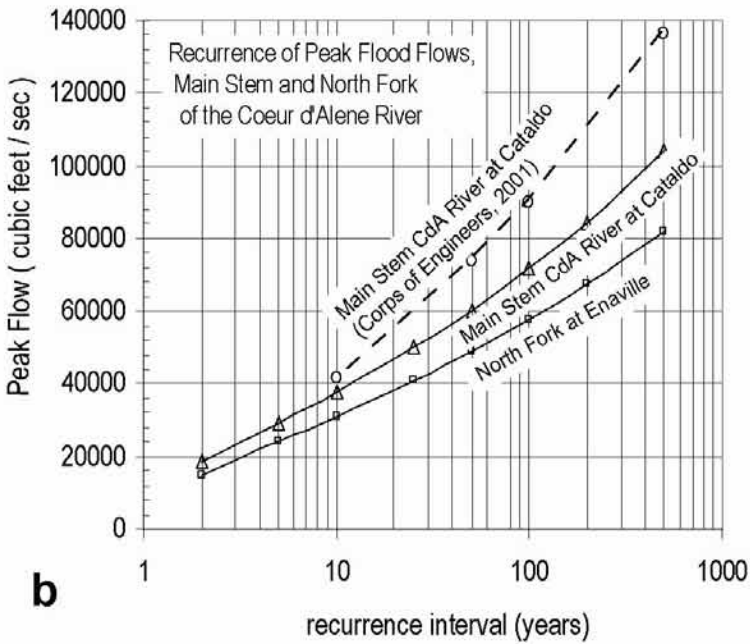
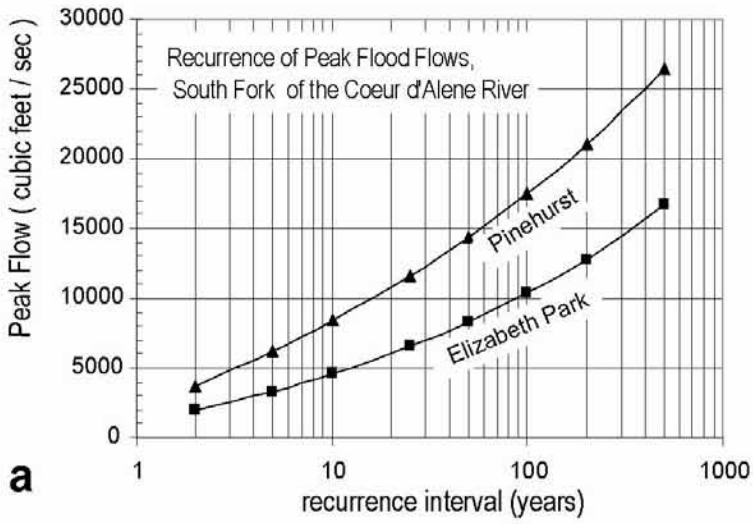


FIGURE 3-6 Coeur d'Alene River flood history, 1886-1997. Annual peak flows and water-surface elevations at Dudley and Cataldo, Idaho, during winter and spring flood events (dashed line depicts flood stage when entire floodplain is inundated). SOURCE: Bookstrom et al. 2004b.

The largest and most damaging floods, however, occur as a result of rain-on-snow storms. The first major flood after the beginning of mining resulted from such an event in December 1933. Now considered to be the 50- to 100-year flood, the peak flow at Pinehurst may have been 17,000 cfs (480 m<sup>3</sup>/s). The floodwaters broke out of diked channels through Kellogg and severely eroded the northeast corner of the Bunker Hill tailings impoundment (Box et al. 1999, p. 5). All the Smelterville Flats north of the railroad were flooded, and tailings were deposited over the flats. However, little of the jig-tailings-aggraded floodplain above Kellogg was flooded.

Another winter flood in January 1974 exceeded that of 1933 and is considered the 100-year flood. Extensive damage occurred where tributary streams enter the South Fork valley, but little overbank flooding occurred along the South Fork. Some damage did occur to dikes, road and railroad embankments, and bridge abutments (Box et al. 1999, p. 12).

A third major winter flood occurred in February 1996. That flood had a peak flow of 11,700 cfs (330 m<sup>3</sup>/s) at Pinehurst, slightly less than the flow of the 1974 flood (Beckwith et al. 1996) and only the floodplains in the bottom reach of the middle basin were inundated by this event (Box et al. 1999, p. 12). The USGS found suspended sediment concentrations of 410-1,900 mg/L during this flood (Beckwith et al. 1996), which indicates that the river could have transported as much as 32,000 metric tons of suspended sediment per day (equivalent to about 20,000 m<sup>3</sup> or 26,000 cubic yards per day).



These rain-on-snow floods are of short duration. Stream discharges increase and peak sharply before they tail off over a few days. These events have produced the largest peak flows of record (1933, 1974, and 1996), reaching 9,600 cfs (270 km/s) at the Elizabeth Park gauge. Multiple-storm winter floods include those of 1917, 1933, 1961, and 1982. Single-storm winter floods include those of 1946, 1951, 1964, 1974, 1980, 1990, 1995, 1996, and 1997 (S. E. Box, USGS, unpublished material, 1994, as cited in Bookstrom et al. 1999, pp. 17-18).

## Groundwater

In addition to the bedrock aquifer and the shallow aquifers found in the upper basin, the middle basin also has a deeper aquifer system within the valley fill separated from the surface aquifer by the relatively impermeable layer of silt and clay (Figure 3-5). The deeper aquifer system begins a little east of Kellogg where it is 20-50 feet (6-15 m) thick and becomes thicker in the lower river reaches. This aquifer is a source of well water for many basin residents who are not on municipal systems that obtain their water supply from up-basin surface-water sources. It is recharged by the bedrock aquifers and by seepage through the shallow aquifers. Having been formed before mining began, this aquifer is composed of relatively uncontaminated materials. There is no information about the possibility that groundwater in the aquifer is being contaminated by seepage from the more contaminated waters that lie above it.<sup>6</sup> This aquifer was not evaluated in the 2001 RI (URS Greiner, Inc. and CH2M Hill 2001f, pp. 2-17, 2-18).

---

<sup>6</sup>There is also apparently no information about how many people depend upon this aquifer as a source of water supply although there are a large number (thousands) of private, unregulated drinking water sources in the study area (EPA 2002, Table 6.3-3).

---

FIGURE 3-7 Estimated recurrence of peak flood flows for the Coeur d'Alene River. (a) South Fork at Elizabeth Park and Pinehurst; (b) main stem at Cataldo and the North Fork at Enaville. Solid lines are curves plotted from data of Berenbrock (2002), which considered basin and climatic characteristics and fit log-Pearson type III distribution to peak flow data through 1997. Berenbrock (2002) indicates a standard error of peak flow prediction from 40-70%. The dashed line is the curve plotted from data from the U.S. Army Corps of Engineers (USACE 2001), which derived the flood frequency by separating the winter rain flood and spring snow melt floods into separate flood series by cause (rain- versus snow-melt-generated floods), computing individual frequency curves for each series, and then combining the curves by the probability equation of union into a single flood-frequency curve. Analysis of flood data for the Cataldo gauge indicates that the winter rain-on-snow events dominate the combined frequency curve above the 10-year-flood level. The longest peak-flow record is from Cataldo (1911-1999), and the maximum flood of record was 79,000 cfs in January 1974.

## Dissolved Metals

The bedrock aquifer historically has created some contamination problems, particularly in the adit drainage from the Bunker Hill Mine. This drainage is highly acidic ( $\text{pH} = 2.8$ ), has a high concentration of dissolved metals (110 mg/L of zinc), and has a significant flow rate (3-4 cfs [85-115 L/s]) (Box et al. 1997). The Bunker Hill adit water has been treated to remove metals since the mid-1970s, eliminating what was previously the largest point source of zinc to the South Fork (about 2,000 lbs/day [1,000 kg/day]) (Box et al. 1997). Bunker Hill adit water continues to be treated using the central treatment plant (CTP), and the sludge from the CTP is disposed in an active, unlined containment pond on top of the CIA, located in the Bunker Hill box (EPA 2004b [July 27, 2004]).

Currently, the shallow aquifer systems are the major contributors to the high levels of dissolved metals found in the river, particularly during the low flow periods in late summer and fall when surface water concentrations often exceed 2 mg/L Zn (Clark 2003, Figs. 4 and 6). Infiltration and seepage through the 1-2 m of tailings-contaminated sediments distributed over the floodplain, as well as infiltration into, and seepage from impoundments and tailings ponds contribute high metal loads to the groundwater in the shallow aquifer. Many of the groundwater monitoring wells in the shallow aquifer have total metals exceeding 10 mg/L, most of which is dissolved zinc (TerraGraphics 1996, p. 34-36, 2005). Zinc levels in the Government Gulch area adjacent to the former smelter have exceeded 100 mg/L (EPA 2000, p. 4-9).

In the past, one of the most important sources has been the seepage from the CIA (Rouse 1977). One of the seep areas is so localized that it has created piping and subsidence of the bed of Interstate 90 (Dawson 1998). However, the current and likely future contributions from this source are disputed (EPA 2004c; Rust 2004). These seeps still appear to be discharging into the river under the Interstate 90 embankment (see Rust 2004), but EPA believes that it has largely corrected this problem by installing an impermeable cap on the CIA and diverting the Bunker Hill adit drainage directly to the wastewater treatment plant rather than ponding it on top of the CIA (EPA 2004c). However, water-containing sludge is still disposed into a large unlined pit on top of the CIA. The effect of remedial actions on the metal content of groundwater and metal loads entering the river was uncertain as of 2001 (Borquez 2001; EPA 2000; TerraGraphics 2001). Interim studies suggest some progress in reducing metal loads; however, groundwater remains heavily contaminated in this area, and continued seepage still contributes a high load of dissolved zinc to the river.

Another major source of dissolved metal loadings is groundwater return flow to the river, most of which occurs below the surface of the river.

Typically, the river loses flow to the groundwater in reaches where the valley aquifer widens and regains groundwater return flow (generally with a significant dissolved-metal load) where the valley aquifer narrows. The USGS investigated river-flow losses and metal loading by the return flow along two reaches in the middle basin: a 4.8-mile (7.7-km) reach at Osburn Flats and a 6.5-mile (10.5-km) reach in the Kellogg-Smelterville area (Barton 2002). These measurements were made in July, near the end of the high stream flow and then during the September and October 1999 base flows. For the Osburn Flats reach, Barton (2002) estimated that seepage flow carried 218 lbs (99 kg) of dissolved zinc per day into the river. The Kellogg-Smelterville reach was estimated to contribute 730 lbs (122 kg) of dissolved zinc per day.

EPA had the study of the Kellogg-Smelterville reach reproduced in 2003 after some of the major remedial actions at Bunker Hill had been completed. The new study showed 63% less zinc (464 lbs/day) and 19% less cadmium coming from this reach (CH2M Hill 2004). However, lower groundwater levels in 2003 than in 1999 also may account for some of the difference. The higher 1999 levels could have resulted both in a greater groundwater flux and in the groundwater rising through aquifer materials that previously had substantial opportunity to oxidize, thus making the metal more soluble. It is also possible that in-stream remedial activities occurring during the 1999 study could have released additional dissolved metal into the South Fork of the Coeur d'Alene River.

Substantial additional investigation will have to be completed to obtain a thorough understanding of groundwater-movement dynamics and the incorporation of dissolved metals from the aquifer materials.

EPA estimates that 41% of the total zinc loading in the Coeur d'Alene River as it enters Lake Coeur d'Alene comes from the area included in the box (URS Greiner, Inc. and CH2M Hill 2001i). The increase in zinc loadings as the South Fork travels from Mullan to its mouth is shown in Figure 3-8 and in more detail during the 1999-2000 water year in Figure 3-4. EPA estimates that the river is carrying 23% of the total zinc load when it reaches Osburn. By the time it gets to Pinehurst, it is carrying 78%. The North Fork adds another 7% when it joins the South Fork above Cataldo. The remaining 15% is picked up, presumably from pore water of the river-bed sediments and groundwater seeping through the river banks, between Pinehurst and the mouth of the river at Harrison.

### Ecologic Community

Before the mining era, the valley walls in the middle basin, like the upper basin hills, were heavily forested. Large white pine flourished in the valley bottom, and large red cedars grew in marshy areas. Grassy openings

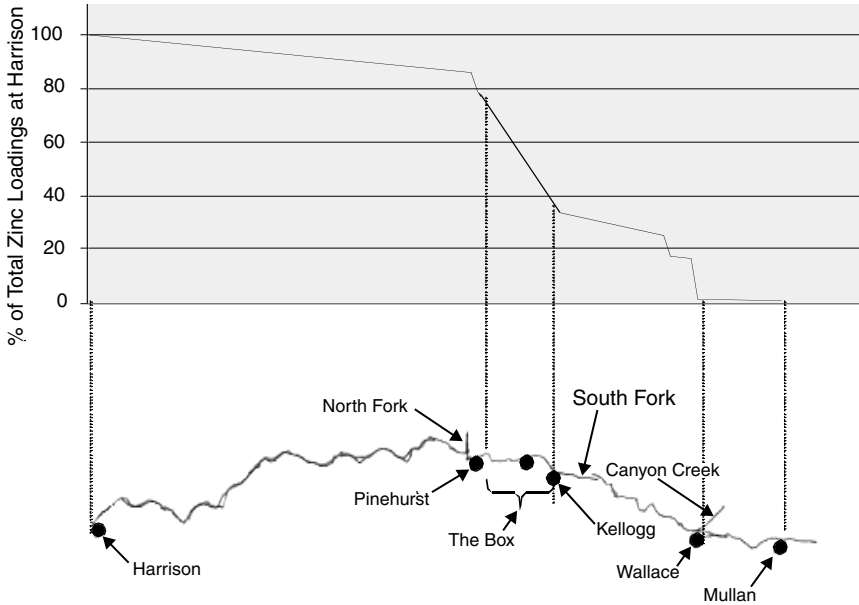


FIGURE 3-8 Zinc loadings to the Coeur d'Alene River as a percent of the total loadings at Harrison. SOURCE: Data from URS Greiner, Inc. and CH2M Hill 2001i.

were sparse (Box et al. 1999, p. 5). The riparian areas also contained alder and large cottonwoods. Wildlife was probably plentiful and diverse, and the waters would have supported large populations of native fish such as cutthroat trout, bull trout, mountain whitefish, and sculpin.

The settlement and establishment of mining activities in the basin substantially degraded all of these habitats. The hills and valleys were logged to provide timber for building structures and for fuel. The river was channelized, blocked, overwhelmed with mine tailings, and contaminated.

As in the upper basin, some of the hill forests have regenerated over the past century. However, the hillsides adjacent to Smelterville, Wardner, and Kellogg are contaminated with heavy metals from smelter emissions (Terra-Graphics 2000; Sheldrake and Stifelman 2003), and an area of about 1,050 acres remained denuded of vegetation in 2000 (EPA 2000, p. 4-21). Soils on these hillsides have high acidity and lack organics and nutrients for native plant revegetation. EPA and the state of Idaho have attempted to replant, treat with lime, and hydroseed these hillsides to reestablish a natural vegetative cover. As of the first 5-year review, however, these efforts have not

been successful in reestablishing ground cover (EPA 2000). Very little reforestation has occurred on the valley floor, much of which is covered by settlements, roads, former mill sites, and waste repositories that support little more than grasses.

Nor has the river channel recovered. Many of the problems created during the 20th century remain and, at least from an ecologic perspective, in some cases, have gotten worse with the increased channel stabilization that has accompanied new construction activities (such as the construction of an interstate highway through the valley), remediation efforts undertaken pursuant to the records of decision (RODs) for OU-1 and OU-2, and attempts to reduce flooding.

Although the middle basin historically has been the most affected by mining activities, fish still exist in this stretch of the river. However, fish-species richness and fish-population abundance are reduced, and sculpins (a species particularly sensitive to metals) are largely absent. No fish are present in the most heavily affected areas (CH2M-Hill and URS Corp. 2001, p. 2–23). The benthic macroinvertebrate community, particularly downstream from the box (as measured by diversity, Ephemeroptera, Plecoptera, Trichoptera [EPT] index, and abundances) has improved through the 1980s, especially after direct discharge of tailings ceased. However, the benthic community remains affected and metal-sensitive taxa (such as mayflies) remain largely absent (Stratus Consulting Inc. 2000).

## THE LOWER BASIN

The lower basin differs in almost all respects from the upper and middle basin of the Coeur d'Alene River. In this reach, the river becomes deeper and takes on a meandering pattern with its bed predominantly composed of sand and silt. The river gradient is nearly flat, and during much of the year the river is essentially an arm of Lake Coeur d'Alene. In low flow, the channel is confined by natural levees bordered by broad floodplains containing wetlands, "lateral lakes," and agricultural lands. The dominant feature of this reach is extensive and rich wetland wildlife habitat, with little human settlement.

### Human Community

Although housing units are scattered along the few roads in the lower basin and some settlements such as Cataldo are located there, the population is small and the U.S. census does not provide any information about communities in the lower basin. The small town of Harrison, located at the mouth of the river, actually lies predominantly outside the lower basin, along the shoreline of Lake Coeur d'Alene and is included with the lake

communities. The committee lacks formal demographic data, but informal observations suggest that the lower basin is a transition zone, reflecting some of the aspects of the communities higher in the basin but also showing signs of being part of the growing recreational development, which characterizes Lake Coeur d'Alene.

### Geology and Fluvial Geomorphology

The dominant geological feature in the lower basin is the change from steep valley walls to broad alluvial floodplains. The floodplains are bordered by steep hillsides, but the hills are relatively low. The lower Coeur d'Alene River valley is essentially the delta of the Coeur d'Alene River into Lake Coeur d'Alene. Here, the lake waters naturally backflood the river channel all the way to the Cataldo Mission. This arm of the post-Ice Age lake was progressively filled with sediment as the delta front (now near Harrison) migrated down-valley. The deep river channel feeding the delta front is carved into earlier fine-grained delta-front lake deposits as it extends down-valley, and the cohesive character of these deposits has inhibited significant lateral migration of the channel through time. Portions of the lake became isolated by the lengthening river channel and its levees, creating what are known as lateral lakes. These lateral lakes gradually shallow and infill with marsh deposits. At Cataldo Flats, the valley-fill sediments are about 160 feet (50 m) thick, and below Rose Lake (less than 10 miles [16 km] below Cataldo), the thickness has increased to 400 feet (120 m) (URS Greiner, Inc. and CH2M Hill 2001j, p. 2-2). The river has a typical meandering pattern in the lower reach, with point bars at the inside of meander bends. Although there are older, prehistoric meander scrolls through the lower reach (Bookstrom et al. 2004a), there has apparently been little channel migration since the mining era began (Box 2004).

The floodplains vary in width from about 1,000 feet (300 m) at Cataldo to about 3 miles (5 km) near the river's mouth. Along the lower reach, distributary streams and man-made canals diverge from the river, connecting to lateral lakes, which range to more than 600 acres (250 hectares), and thousands of acres of wetlands. The soils here are rich enough to support substantial wetlands vegetation. Approximately 9,500 acres (3,800 hectares) of floodplain along this reach have also been converted to agricultural use (CH2M-Hill and URS Corp. 2001, p. 2-29).

The metal-contaminated deposits on the floodplain of the lower segment are thinner than those along the middle stretch and generally are composed of finer materials. Metal-enriched levee silt and sand deposits extend across bank wedges and natural levees, generally thinning to 1.5 feet (0.5 m) at a distance of about 260 feet (80 m) from the channel banks (see Figure 3-9) and fining away from the river, toward lateral marshes and

lakes. In these lateral marsh areas, approximately 6-17 inches (15-44 cm) of dark gray, metal-enriched silt and mud overlie the silty peat deposited before the mining era (Bookstrom et al. 2001, p. 24). The soil near the distributary streams and man-made canals carrying water to these lakes and wetlands may be covered by thicker and metal-enriched sand splays deposited by floods as they overtop the river banks. These splays fan out across the floodplain, typically cover a couple of hundred acres (about 100 hectares), and are several meters thick near the river, tapering to less than 1.5 feet (0.5 m) at their end (Bookstrom et al. 2001, p. 25, Fig. 8).

Another location with heavily contaminated sediment cover is Cataldo Flats, where the mining companies deposited contaminated materials dredged from the river channel. These dredged materials cover 2,000 acres (800 hectares) to a depth of 25-30 feet (7.5-9 m) (URS Greiner, Inc. and CH2M Hill 2001j, p. 2-6). During the first 2 years of operation, the dredge removed 1.8 million metric tons (2 million U.S. tons) of material from the channel, but each year the channel filled up again during the flood season (URS Greiner, Inc. and CH2M Hill 2001j, p. 2-6). The dredge continued operating until 1968.

The river channel has much thicker layers of contaminated sediments covering the premining materials. This contaminated channel sand is typically 9 feet (2.6 m) thick across the 260-foot (80 m)-wide channel (Bookstrom et al. 2001, p. 23). The fact that the channel deposits are substantially thicker than the floodplain deposits suggests that the premining river channel in this reach was much deeper than it is today. This is supported by a 1932 report quoting steamboat operators who remembered the channel being navigable “with 40 to 50 feet of water” (12-15 m) up to Cataldo

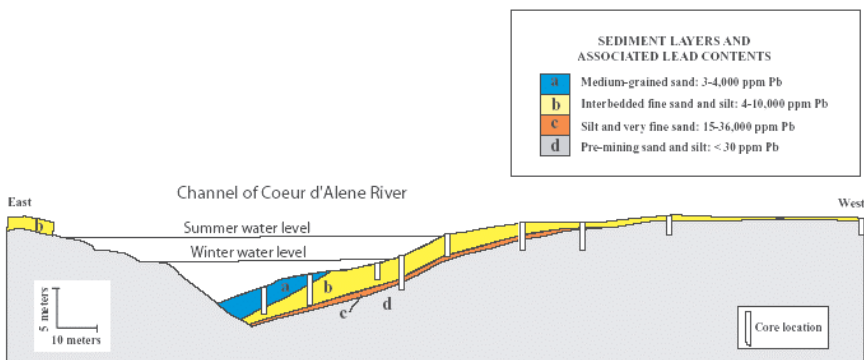


FIGURE 3-9 Cross-section of Coeur d'Alene River near Killarney Lake showing lead content of sediments in cores from the channel and floodplain. SOURCE: Balistrieri et al. 2002a.

(URS Greiner, Inc. and CH2M Hill 2001j, p. 2-6). By 1932, the river had “only 12 to 15 feet (3.5 to 4.6 meters) of water in the main channel in this region, both the channel and the main stream being obstructed here and there by large bars of mine wastes and tailings” (URS Greiner, Inc. and CH2M Hill 2001j, p. 2-5).

The USGS estimates that the river bed contains 51% of the lead in the entire lower basin (Bookstrom et al. 2001, Table 12). These channel deposits are mostly silty fine-to-medium sand (Bookstrom et al. 2004b, slide 22; Box 2004, slide 19).

Metal-enriched sand and silt also form oxidized bank-wedge deposits along the river channel, covering the premining-era levees of gray silty mud. However, the metal content of bank material at the upper end of the lower basin is relatively low (about 2,000 mg/kg) (compared with bank deposits in other reaches) as a result of the contaminated sediment carried by the South Fork being diluted by the clean sediment coming in from the North Fork (Box 2004, slide 28).<sup>7</sup> The volume of riverbank material is about 1.7 million cubic yards (1.4 million m<sup>3</sup>), and it contains 4% of the lead in the lower basin (Bookstrom et al. 2001).

The remaining 45% of the lead in the lower basin is in the subaerial levees (10%), in sediments spread over the floodplain and deposited in the lateral lakes and marshes (18%), or in the dredge soils on Cataldo Flats (17%) (Bookstrom et al. 2001; Box 2004). The only wetlands and lateral lakes in the lower basin that do not receive frequent deposits of contaminated sediments are those located south of the railroad embankment, which forms a protective levee (Bookstrom et al. 2004a). In the 1999-2000 water years, approximately 80% of the lead load transported to the lake at Harrison was derived from the main stem river below the confluence of the North and South Forks (Clark 2003, Fig. 12). The peak flow in that year was about 27,000 cfs or a spring flood with a 3- to 4-year recurrence (Figure 3-7).

The preceding discussion suggests that the major source of high-metal-content sand and silt remobilized during floods is bedload scoured from the channel and that the main-stem channel, therefore, is a major source of metal-contaminated material that is delivered to the lateral lakes, marshes, and Lake Coeur d’Alene.

Complicated chemical processes occur once the sediments are deposited in the oxygen-scarce wetlands and lake bottoms. These processes tend

---

<sup>7</sup>However, by 11 km downstream of the confluence, the recent-flood-deposited bank material again has a high metal concentration (4,500 parts per million). It appears that the high-metal-content sandy bank deposited in the 1995 and 1996 flood flows in the lower main stem is derived mostly from scouring and redepositing the high-metal-content channel material (Box 2004, slide 28).

to make the metals more biologically available as described in a recent USGS report (Bookstrom et al. 2004a):

In reducing environments of marshes and lakes, metallic oxy-hydrides, transported from oxidizing environments on levee uplands, are reduced. Reduction breaks down metallic oxy-hydrides and releases metallic ions, which combine with sulfide ions (produced by sulfate-reducing bacteria) to form authigenic sulfidic-metallic materials that are non-stoichiometric and amorphous to nano-crystalline. These materials have enormous surface area, and are much more chemically reactive than detrital grains of crystalline metallic sulfide minerals. The lead in these authigenic sulfides is therefore much more bio-reactive and bio-available than the lead in detrital grains of galena.

### Hydrology

The flow of the main stem of the Coeur d'Alene River is gauged at Cataldo, where the mean annual flow for the 1911-2003 record is 2,531 cfs (72 m<sup>3</sup>/s), with late summer flows below 500 cfs (14 m<sup>3</sup>/s) (USGS 2004). Flow in the lower main-stem channel is nearly imperceptible for most of the summer and fall. Bank erosion during this period occurs from waves generated by wind and boat wakes. Because these low flows result primarily from groundwater discharge, they contain high levels of dissolved contaminants such as zinc.

Since 1886, 13 major floods have inundated the floodplain of the Coeur d'Alene River valley, and 26 lesser floods have flooded much of the valley floor (Figure 3-6). Since mining began, the extent and severity of overbank flooding has probably increased as a result of channel aggradation caused by sedimentation of mine wastes and reduced forest cover. During flood flow, the river breaks out into natural or artificial channels and through levee breaches to the large lateral marshes and lakes. During large floods, levees are overtopped and most of the valley floodplain is inundated. Such overtopping is relatively common, having a recurrence period of 1.5 years (URS Greiner, Inc. and CH2M Hill 2001j, p. 2-14).

Because the floodplain of the Coeur d'Alene River generally slopes away from the tops of the natural levees that flank the river, if floodwater overtops the levees or flows through low passes in the levees, it tends to cover most of the floodplain. Annual spring floods commonly inundate the lower valley, and major spring floods inundate most of the floodplain. The more severe rain-on-snow winter floods commonly occur when the lake level has been drawn down so that the hydraulic differential in the segment is unusually high. One result of this difference is that a given amount of winter flood flow is less likely to overtop the river levees than the same amount of spring flow. However, because the winter rain-on-snow floods

usually move more quickly, they are likely to scour more tailings sediments from the channel and, if they do overtop the levees, deposit them on the floodplain.

### Ecologic Community

Before mining began, the natural levees along the lower reach of the river would have been extensively forested with cottonwood and alder trees. These natural vegetative types continue to exist today, although probably in less abundance because of the covering of the natural levees with contaminated sediment and man-made alterations along the banks for recreational and other purposes. The wetlands and uplands vegetation in the downstream reach of the Coeur d'Alene River were not significantly affected by the mining operations. However, extensive areas have been cleared and drained for agricultural purposes (for pasture and cropland) and for urban and recreational development.

The lateral lakes and wetlands provide areas for waterfowl nesting, feeding, and other activities. Twenty-five species of waterfowl have been identified in the vicinity of the lateral lakes during spring and fall migrations, and more than 280 bird species are found throughout the Coeur d'Alene River basin (CH2M-Hill and URS Corp. 2001, p. 2-17). As described in Chapter 7, the contaminated sediments are implicated in the poisoning of many waterfowl every year and may be having negative impacts on other species of birds using these habitats (CH2M-Hill and URS Corp. 2001, p. 2-25).

Tundra swans are particularly vulnerable to lead exposure and intoxication for multiple reasons. In particular, swans that occupy the Coeur d'Alene River basin to a large degree are either en route to the northern breeding grounds during their migratory period or heading south during wintering periods. Therefore, when they arrive in the Coeur d'Alene River basin, they are searching for available habitat, particularly for food and resting areas. With their long necks, tundra swans can, as they feed, easily reach sediments beneath a meter of water. In the process of sifting through sediments, often searching for root tubers and other food products, tundra swans ingest sediment. In the Coeur d'Alene River basin—in particular the lateral lakes feeding areas—the sediment can be heavily contaminated with lead. With such feeding habits, and with their preference for the habitats of the lateral lakes which are heavily contaminated, tundra swans are at a great risk. The risk is confirmed by substantial data on swan mortality in the Coeur d'Alene Ecological Risk Assessment (CH2M-Hill and URS Corp. 2001). See further discussion in Chapter 7 of this report.

The main stem of the Coeur d'Alene River holds many species of fish, including native salmonid species and several exotic (that is, introduced)

species such as rainbow trout, chinook salmon, bass, tench, northern pike, and tiger muskellunge, although apparently there is not enough information to determine the status of the fish populations (URS Greiner, Inc. and CH2M Hill 2001i, p. 2-24) or the diversity and abundance of benthic macroinvertebrates.

Numerous cold-water and warm-water fish species inhabit the lateral lakes and the Idaho Department of Fish and Game actively manages a warm-water fishery in several of these lakes. Populations of 19 nonnative fish species, such as rainbow trout, chinook salmon, bass, tench, northern pike, and tiger muskellunge, have been introduced into these lakes as well as the main stem of the river. These introductions have substantially altered the dynamics of the system (CH2M-Hill and URS Corp. 2001, p. 2-24) and have complicated the effort to protect many native species such as cutthroat trout (for example, through the introduction of predators).<sup>8</sup>

## LAKE COEUR D'ALENE

Lake Coeur d'Alene is a large body of water approximately 25 miles (40 km) long with a width of 1-2 miles (1.6-3.2 km) along most of its length. The lake has a surface area of approximately 50 square miles (130 km<sup>2</sup>) and 133 miles (215 km) of shoreline. The lake has become a heavily used tourist and recreational facility—for both boating and fishing—for residents throughout the Northwest.

### Human Community

Most of the shoreline of Lake Coeur d'Alene is relatively unpopulated, although residential development on the shoreline is increasing. There are a few settlements at the south end of the lake, which lies within the reservation of the Coeur d'Alene tribe, but the only two communities included in the U.S. census are Harrison (at the mouth of the Coeur d'Alene River) and the city of Coeur d'Alene (at the north end of the lake). Table 3-3 summarizes some of the demographic characteristics of these communities.

Harrison shows the same high poverty rates and older population as the communities in the middle and upper basin, but the housing stock is generally newer. It is experiencing a rapid influx of new residents, a greater percentage of residents has graduated from college, and the median income is substantially higher.

---

<sup>8</sup>The Natural Resources Damages Assessment found only 11 species of native fish in the Coeur d'Alene basin compared with 19 species of nonnative fish found there (Stratus Consulting, Inc. 2000).

The city of Coeur d'Alene, however, is a relatively large community that has been growing rapidly (a 73% increase from 1980 to 2000) (Idaho Department of Commerce 2004). The median age of the population is below the national average, although almost 15% of the residents are more than 65 years old, suggesting that the community is becoming a retirement community. The median household income is substantially higher than that of other communities in the basin, although it is below the Idaho and national averages. The poverty rate and the unemployment rate were lower than those for basin communities, and, most dramatically, almost 30% of the housing units were built after 1990, and almost 80% of the residents had been living in their homes for 10 years or less in 2000. This rapid growth and change has been fueled largely by growth in tourism and recreational developments. This trend has been echoed in much of the area around the northern end of the lake with the construction of vacation homes.

The reservation for the Coeur d'Alene tribe encompasses the southern part of the lake. The U.S. census found 4,465 people living on the reservation in 2000, and about 17% of those identified themselves as American Indians (U.S. Census 2004).

### Geology and Geochemistry

Lake Coeur d'Alene was created by the catastrophic glacial-outbreak floods from the Pleistocene Lake Missoula. These floods filled the lower Coeur d'Alene River Valley with coarse outwash forming a massive dam blocking the river near the city of Coeur d'Alene. The lake filled behind this

TABLE 3-3 Demographic Characteristics of Lake Coeur d'Alene Communities

Demographic	U.S.	Idaho	Harrison	Coeur d'Alene
Population			267	34,514
Median age (years)	35.3	33.2	46.1	34.8
Older than 65 (% of population)	12.4	11.3	19.5	14.8
Household income (\$ thousands)	42.0	37.6	35.8	33.0
Unemployment rate (%)	5.8	5.8	7.3	7.9
Below poverty level (% individuals)	12.4	11.8	20.3	12.8
% with bachelor's degree	24.4	21.7	29.4	19.5
Moved from out of state since 1995 (%)	8.4	15.3	25.1	21.8
% of owner occupied units occupied by the same family for >30 years (%)	9.7	6.9	7.4	4.6
Vacant housing units (%)	9.0	11.0	21.0	6.3
Houses older than 40 years (%)	35.0	27.7	46.5	28.2

SOURCE: U.S. Census 2004.

natural dam, flooding the valleys of the Coeur d'Alene River and the St. Joe River (the lake's other major tributary) to the south. Except near its outlet and the mouths of its major tributary rivers, the banks of the lake are formed by the rock of the ancient valley walls, rising to low hills.

The maximum depth of the lake exceeds 200 feet (61 m), and its average depth is 70 feet (21 m). The Pleistocene lake was originally somewhat higher than it is now, extending up to about Kellogg (Box et al. 1999, p. 5). The erosion of the channel through Missoula flood gravels by the Spokane River gradually lowered the lake's surface elevation to the bedrock at Post Falls. The lake level was then raised slightly with the construction of a dam at Post Falls in 1906.

The Coeur d'Alene River has carried immense amounts of sediment—containing 300-400 thousand metric tons (350-440 thousand U.S. tons) of lead—into the lake (Bookstrom et al. 2001, Table 15). Horowitz et al. (1995a) estimated that 75 million metric tons (83 million U.S. tons) of metals-contaminated sediments had been deposited on the bottom of Lake Coeur d'Alene since the onset of mining. The coarser sediments tend to settle near the point where the river enters the lake, forming 20-foot (6-m)-thick delta-front deposits of metal-enriched sand that slope from the river-mouth bar almost a kilometer (0.6 mile) from the delta front to the bottom of the lake (Bookstrom et al. 2001). Finer sediments have been carried farther into the lake, creating a metal-enriched sediment layer up to 119 cm (3.9 feet) thick closest to the Coeur d'Alene River delta, thinning to 10-14 cm (4-5.5 inches) near the city of Coeur d'Alene<sup>9</sup> (Horowitz et al. 1995a).

Lake-bottom sediment samples (one sample per km<sup>2</sup>) have a mean lead concentration of 1,900 mg/kg but range up to 7,700 mg/kg (Horowitz et al. 1993, p. 410, 1995b). Nearshore areas show much lower levels. For instance, seventeen beaches and common-use areas along Lake Coeur d'Alene tested for lead contamination showed an average lead concentration of less than 200 mg/kg for all sites except Harrison Beach, which averaged 1,250 mg/kg (URS Greiner, Inc. et al. 1999). Harrison is adjacent to the mouth of the Coeur d'Alene River where, as indicated above, the deposition of sediment from the river continues to build a large delta out into the lake.

Some of the fine contaminated sediment is carried completely across the lake and into the Spokane River. This process is particularly evident during spring floods (see Chapter 4 of this report for further discussion).

---

<sup>9</sup>Very little contaminated sediment has been found in the far southern part of the lake. However, some landowners in this area are concerned about possible contaminants leaching out of the railroad embankment and causing serious localized contamination problems (Hardy 2004). The committee's charge did not include evaluation of this issue, and the committee has not evaluated it.

EPA estimated that in water year 1999, approximately 50% of the dissolved zinc input was converted into the particulate form within the lake (URS Greiner, Inc. and CH2M Hill 2001k, p. 5-90), which presumably settles to the lake bottom. Soluble zinc within the lake will interact with biotic and abiotic components in the water column that are capable of affecting the disposition and transport of the metal. For instance, soluble zinc coming from the Coeur d'Alene River will associate with phytoplankton (and become sorbed to the organic matrix of the cell or incorporated into the silica in diatom frustules). Upon dying, the phytoplankton fall out of the water column and become incorporated in sediments. Zinc also may associate with dissolved or particulate organic matter or with inorganic species, particularly ferric oxyhydroxides. Samples taken from the lake bottom contain a ferric oxyhydroxide flocculent material that is enriched in zinc (Woods 2004).

The fate of the zinc within the sediments is complex, related to the oxic state of the sediments and the geochemical associations. The zinc can remain bound to organic or inorganic substrates, or it can become soluble after oxidation. The oxidation of organic matter in the sediment requires a terminal electron acceptor. Oxygen and nitrate, both electron receptors, become depleted near the sediment-water interface. Below this, sulfate becomes reduced to sulfide. The sulfide reacts with iron and trace metals, such as cadmium, copper, lead, and zinc (Di Toro 2001), which results in the formation of amorphous metal monosulfide precipitates, such as FeS, PbS, and ZnS, that will effectively sequester zinc.

The solubility of FeS is greater than that of CdS, CuS, PbS, and ZnS. Consequently, FeS is a reservoir that provides sulfide to react with cadmium, copper, lead, and zinc. The solubility of metals from the metal monosulfides is less than that of the metals associated with ferric oxyhydroxide or particulate organic matter. There are limited data for the lake sediments in which this speciation has been determined. Tests that have been conducted suggest that not all the zinc and lead are present as ZnS and PbS, but that some metal is contained in other forms, likely associated with ferric oxyhydroxide or particulate organic matter (Harrington et al. 1999; Horowitz et al. 1995a; see Chapter 4 for further discussion).

The geochemistry of the lake bottom is of concern because the processes occurring there determine the extent to which the metals in the contaminated sediments will become biologically available and thus a risk to the fish and benthic populations. If the metals remain in the insoluble form, these risks are reduced. Maintaining a lake environment that will keep these metals insoluble is a primary goal of a lake management plan being developed (see Chapter 8 of this report).

### Hydrology

With the construction of Post Falls Dam in 1906, the control gates allowed the lake level to be raised 6-7 feet (2 m). In 1940, the dam was raised another foot (0.3 m). The dam gates are used to reduce outflow from the lake and to control lake level at a fixed elevation from about June to September. In September, the power company manipulates the gates to increase the outflow rates for power generation and cause the lake level to fall about 1.5 feet (0.5 m) per month until mid-November to provide storage capacity for spring runoff. From mid-November to May or June, the gates are fully open, and the lake seeks its natural low winter level. After spring runoff, the gates are again used to control outflow and lake level.

Lake levels are also affected by flood flows entering the lake from the Coeur d'Alene and Saint Joe Rivers (see Figure 3-10). These floods can raise the water level 12-14 feet (about 4 m). The 1933 flood raised the lake level 19 feet (5.8 m) above the winter low (Kootenai County 1998).

In 1999, USGS investigators also observed the spring flood with its suspended sediment load coursing across the surface of the lake to the Spokane River (Woods 2004). They hypothesized that this occurs because the river waters warm faster than the lake waters and, therefore, essentially float

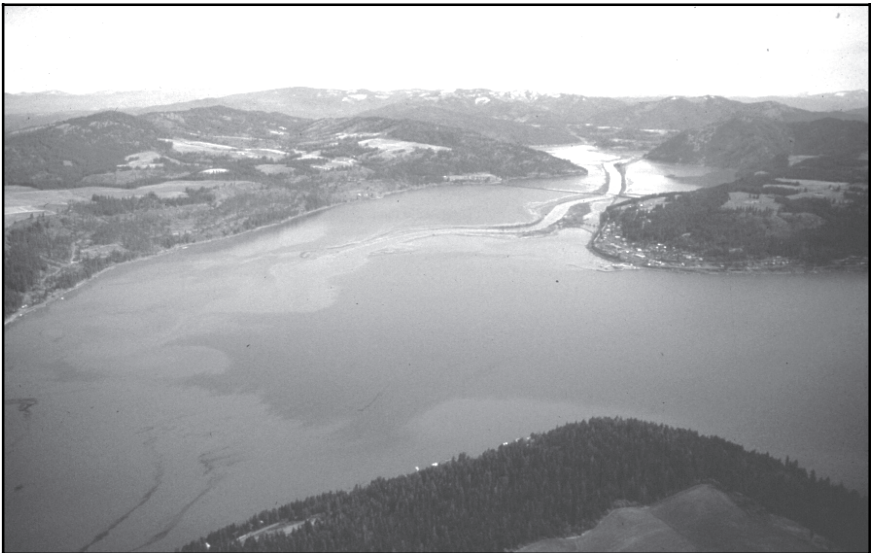


FIGURE 3-10 Coeur d'Alene River delta and inflow plume adjacent to Harrison, Idaho, on Lake Coeur d'Alene. SOURCE: Woods 2004.

across the surface of the lake. They intend to do more research to document this phenomenon. The existence of these flows would indicate that more contaminated sediment is being delivered to the Spokane River than otherwise might be expected (see Chapter 4 of this report for further discussion).

### Ecologic Community

Lake Coeur d'Alene is home to a diverse mix of both cold-water and warm-water species of fish. Several of these fish, however, are exotic species that were artificially introduced there. The populations of at least some of the native species (westslope cutthroat trout, bull trout, mountain whitefish, yellow perch, northern pikeminnow) are probably being stressed by the introduced species.

The richness and abundance of the benthic community is greatest in the shallow waters and at the southern end of the lake, below the mouth of the Coeur d'Alene River. However, EPA concludes that there is no good evidence that these differences are caused by the deposition of contaminated sediments (CH2M-Hill and URS Corp. 2001, pp. 2-26 to 2-27). Some of the difference may result from the higher nutrient loads in the southern portion of the lake. Nevertheless, the contaminated sediments provide at least a potential threat to the benthic community and fish life. The extent of this threat will, as discussed above, depend significantly on geochemical reactions taking place on the lake's bottom. The responses of benthic invertebrates to the metal-contaminated Lake Coeur d'Alene sediments have been studied only minimally (Hornig et al. 1988; CH2M-Hill and URS Corp. 2001, p. 2-26) as has the relationship of benthic communities to the presence of metals within sediments. Further, although the metal flux has been investigated, there has been no study of the influence of invertebrates on the bioavailability of metals in Lake Coeur d'Alene, a potentially important factor in metals dynamics (Kennedy et al. 2003).

### SPOKANE RIVER

The Spokane River drains Lake Coeur d'Alene at its northern end through the Rathrum Prairie to Post Falls, where it spills over the Post Falls Dam and cascades over a natural 40 foot (12 m) bedrock waterfall. From Lake Coeur d'Alene, the Spokane River flows at a relatively flat gradient through a 3- to 8-mile (4.8- to 12.8-km)-wide valley extending westward to the junction with the Little Spokane River. Along this route, the river flows over five more dams, four of which are within the city of Spokane (URS Greiner, Inc. and CH2M Hill 2001, p. 2-7). At its lower end, the valley narrows, and the river is largely contained in the reservoirs behind Long Lake Dam and Grand Coulee Dam.

Human Community

The city of Spokane, with a population close to 200,000 in the year 2000, is the largest community along the Spokane River. The unincorporated area of Opportunity, Washington, with a population of 25,000, and Post Falls in Idaho, with a population of 17,000, are other large communities (Table 3-4). Post Falls demonstrates many of the same demographic characteristics as the city of Coeur d'Alene—for instance, a very rapid growth rate and a relatively young population. The population growth in Spokane and Opportunity is much lower, although these communities have also grown slightly faster than the national average.

All these communities use the Spokane aquifer as their primary source of drinking water (URS Greiner, Inc. and CH2M Hill 2001l, p. 2-6). This aquifer covers the entire valley and extends from the bedrock below the valley as much as several hundred feet up to the surface. Lake Coeur d'Alene and the upper Spokane River are primary sources of recharge to this aquifer.

The reservation for the Spokane tribe lies along the lower part of the Spokane River where it joins the Columbia River. According to the U.S. census, approximately 2,000 people lived on the reservation in 2000.

The River and Its Contamination

When not contained in a reservoir, the Spokane River above the city of Spokane is 200-400 feet (60-120 m) wide with a gravel bottom and many of the characteristics of a braided stream (URS Greiner, Inc. and CH2M Hill 2001l, p. 3-3). Because of the substantial hydraulic buffering capacity

TABLE 3-4 Demographic Characteristics of Larger Communities Along Spokane River

Demographic	U.S.	Idaho	Post Falls	Opportunity	Spokane
Population			17,247	25,065	195,629
Median age (years)	35.3	33.2	31.3	35.8	34.7
Older than 65 (%)	12.4	11.3	9.8	14.8	14.0
Household income (\$1,000)	42.0	37.6	39.1	38.7	32.3
Below poverty level (% individuals)	12.4	11.8	9.4	9.0	15.9
% with bachelor's degree	24.4	21.7	15.9	20.3	25.4
Moved from out of state since 1995 (%)	8.4	15.3	26.1	9.8	10.1
Vacant housing units (%)	9.0	11.0	4.9	5.4	7.3

SOURCE: U.S. Census 2004.

of Lake Coeur d'Alene, the substantial variations in the flows experienced in the Coeur d'Alene River are not reflected in the Spokane River. Indeed, the Lake is managed by allowing the water level to fall during the winter so that it can store the spring flood flows and reduce downstream flooding. As a result, the flood with a 100-year recurrence interval is projected to carry only slightly over a third more water than the 10-year flood (URS Greiner, Inc. and CH2M Hill 2001l, Table 2.3-1).

The RI states that the Spokane River water frequently exceeds water-quality standards for zinc, lead, and cadmium (URS Greiner, Inc. and CH2M Hill 2001l, p 5-1). The major source of these metals is the outflow from Lake Coeur d'Alene.

Some of the lead is contained in fine sediment that traverses Lake Coeur d'Alene during the spring runoff. This sediment comes predominantly from the channel in the lower basin of the Coeur d'Alene River (Clark 2003). The re-suspension of previously deposited sediments is another major source (Grosbois et al. 2001; Box and Wallis 2002). The sediment is largely deposited behind the upstream dams, along shoreline beaches, and in backwaters behind channel obstructions. Concentrations of lead exceeding 2,000 mg/kg have been measured in shoreline sediment (EPA 2002, Table 7.1-21). Elevated arsenic levels, also a source of concern, are generally associated with high lead levels. Polychlorinated biphenyls, which are not derived from mining wastes, are also a contaminant problem in the Spokane River (EPA 2002).

Approximately 70% of the dissolved zinc entering Lake Coeur d'Alene flows out into the Spokane River, resulting in total annual dissolved zinc loadings ranging from 225,000 kg (496,000 lbs) to 767,000 kg (1,690,000 lbs) per year (URS Greiner, Inc. and CH2M Hill, 2001k, p. 5-4; Clark 2003). The dissolved zinc concentrations exceed ambient water-quality standards throughout most of the year and remain relatively constant through the upper part of the river down to the city of Spokane. Below Spokane, they decrease to the point where water-quality standards are not exceeded in Long Lake (URS Greiner, Inc. and CH2M Hill 2001l, p. 5-7, 5-8). Unlike the situation in Coeur d'Alene River, the zinc concentrations (as well as the zinc loadings) increase with increased discharge (URS Greiner, Inc. and CH2M Hill 2001l, p. 5-8).

### **Ecologic Community**

The several dams along the Spokane River provide artificial lacustrine (lake) habitats with substantial fish populations but, at the same time, interfere with the migration of salmonid species. Most of the river has limited (narrow and sparsely vegetated) riparian habitat and very little palustrine (wetland) habitat (CH2M-Hill and URS Corp. 2001, p. 2-20).

However, the shorelines around some reservoirs such as Long Lake and Nine Mile Reservoir do have substantial riparian vegetation (CH2M-Hill and URS Corp. 2001, p. 2-29).

The diversity of benthic invertebrates is lower than normally would be expected for a river like the Spokane (CH2M-Hill and URS Corp. 2001, p. 2-24), but the fish community is "diverse and moderately productive" (CH2M-Hill and URS Corp. 2001, p. 2-25). More than 20 species of fish have been identified, although many of these, like the rainbow trout, have been artificially introduced into the river for recreational purposes.

## LOOKING AHEAD

This chapter has focused primarily on the current conditions in the basin and the historical events that have led up to them. However, particularly for a project that will take decades, and perhaps even centuries, to implement, it is important to consider how these systems might change in the future.

If current trends were to continue, the basin would expect over a long period, to experience three major changes in the conditions described above. The first would be continued regeneration of the forests on the basin slopes and the slow recovery of some of the riparian areas. This would result in decreased runoff and erosion during precipitation events, would likely reduce the magnitude of the normal late spring floods by slowing the rate of snow melt, and could reduce the floods resulting from rain-on-snow events by partially insulating the snow from the warm air masses that accompany these events.

The second change would result from the continuing erosion of the mine tailings and other materials deposited in the upper valleys and the deposition of these materials in the middle and lower segments as well as Lake Coeur d'Alene and the upper Spokane River. Ultimately, the erosion in the upper basin and sedimentation rates in the middle basin would diminish, and channels would stabilize, particularly if the riparian areas are allowed to recover and the stream reaches return to mostly transport reaches as they were before mining.

The lower basin, however, is unlikely to return to its premining condition. Sedimentation will continue at lower rates in the lower basin floodplain and wetlands. Over millennia, the lateral lakes would become marshes, and the marshes would become floodplain grass and brush areas used for fields and pastures. Bookstrom et al. (2004a) indicate pre-mining depositional rates of about 1 mm/year in the open-water environment of Killarney Lake. The post-1980 rates are about 4 mm/year. At Medicine Lake, pre-1968 depositional rates exceeded 8 mm/year but have since declined to 4 mm/year (Bookstrom et al. 2004a). Some marsh areas with substantial

accumulation of peat do not have high levels of lead, and the slow conversion of lake to marsh ultimately may cover some of the contaminated areas.

The delta would continue to build lakeward, creating new lateral lakes and marshes on the flanks of the leveed channel. The fate of the large inventory of contaminated sediments in the channel of the main stem is uncertain. The historic channel has not migrated, but it is subject to scour and remobilization of bed material. This process would be substantially influenced by the relative prevalence of serious rain-on-snow flooding events compared with the normal flooding pattern resulting from late spring snow melt. The latter results in more deposition, and the former is more likely to carry its sediment into (and across) the lake.

The third trend would be declining loadings of zinc and other dissolved metals in the downstream segment of the river as the available supplies of soluble metals diminish in the upper and middle segments.

It is also unclear what will happen in Lake Coeur d'Alene. It will continue to receive sediments, which will extend the delta of the Coeur d'Alene River farther out into the lake and increase the depth of contaminated sediments on the lake bottom. The major question is whether the lake will become more eutrophic, and, if so, what effects this will have on the lake's chemistry and biota. There is substantial concern that changes in the lake's chemistry could result, as indicated in the above description of Lake Coeur d'Alene, in the release of contaminants currently bound in the sediments coating the lake bottom. These released contaminants could be toxic to fish and other aquatic biota and, therefore, in conjunction with the other effects of eutrophication, could cause significant changes in the lake's biological systems.

The Spokane River would continue to receive some of the sediment carried down the Coeur d'Alene River, necessitating continuing cleanup of contaminated riparian recreation areas and resulting in a gradual filling in of the reservoir behind Upriver Dam.

All these processes would continue over a period of centuries, and none of the possible changes is likely to occur in the near term except, perhaps, those that might occur in Lake Coeur d'Alene. There is no reason to expect any natural perturbations that might significantly disrupt these processes, although serious forest fires in the basin could temporarily disturb them, as would a major volcanic ash fall from an eruption in the Cascades or Yellowstone.

The most significant possible perturbations are likely to result in the future, as they have in the past, from human activities. Some could occur within the project area; others are likely to occur more globally.

### **Local Human-Induced Perturbations**

Within the basin, it is conceivable that substantial increases in metal prices could stimulate increased interest in mining opportunities. As indicated earlier,

some mines have continued to operate in the basin, and plans are currently in place for expanded activities. Other mines probably could be brought back into production under extremely favorable economic conditions (or as a result of government demands such as occurred during World War II). Even if this were to occur, however, it is unlikely that any future mining activities would have as much impact on the basin as the historical mining activities did, primarily because the mines are now prohibited from disposing of their mining wastes in such an environmentally destructive manner.

One particularly remote possibility under the increased mining scenario is that metal prices would rise so high as to support the remining of the old tailings and other wastes containing low concentrations of metals. Such remining is occurring in old gold mining areas in the West (see NRC 1999) and is arguably reducing environmental risks at these sites. In the Coeur d'Alene River basin such remining activities conceivably could result in the removal of large amounts of contaminated materials from some of the stream channels as well as the tailings piles and other terrestrial deposits. This possibility, however, is diminished not only by the likely adverse economic conditions but also by the fact that the basin has been designated a Superfund site with all the liabilities associated with such a designation.

A much more likely development pattern in the basin is for it to become a center for outdoor recreational activities and leisure home developments. Lake Coeur d'Alene already has experienced substantial development of this type, and the demand for these developments continually increases with rising incomes in the United States. Both the natural beauty and the historical significance of the Coeur d'Alene basin make it an attractive location for such developments to occur.

Such recreational developments could significantly change socioeconomic conditions in the basin, bringing higher-income residents and economic stimulus for the basin's merchants and labor force. If properly controlled, such developments need not generate significant environmental damage, and their residents may be highly sensitive to the quality of the environment. There would undoubtedly be some erosion associated with the new construction, and recreational demand could also result in the construction of access roads and even the clearing of large areas for snow sports. Both could result in increased runoff and erosion, with the concomitant increase in downstream floods and sedimentation.

Although some valley residents fear that the potential for these recreational developments will be diminished by the designation of the valley as a Superfund site, the elimination of significant health risks as a result of the Superfund cleanup might make the valley more attractive to these potential residents. Support for this hypothesis is provided by the proposal announced this year for building a major recreational facility near Kellogg within the area that was designated a Superfund site in 1983 and that has since been largely cleaned up under the Superfund program (Kramer 2004).

Another economic change that could occur in the more distant future is the relogging of the forests in the basin after they have regenerated. As discussed earlier in this chapter, the intensive management of the forests in the North Fork basin is already thought to be increasing erosion and runoff there. And, considering the massive amounts of metal-contaminated sediments that can be remobilized during large floods (especially the scouring of highly contaminated and deeply buried riverbed sediments), water retention and yield from the watershed is a significant issue. Ironically, the increased transport of relatively clean sediment from the North Fork is reducing the average concentration of lead in sediments below its confluence with the South Fork.

### Regional and Global Human-Induced Perturbations

One possible perturbation that could occur at the regional level is an increase in acid rain resulting from electrical power generation, increased vehicle traffic, or other sources. However, it is unlikely that this would become a significant problem in the Coeur d'Alene River basin, and the neutralizing effects of the basin's soils would largely prevent any serious effects.

At a global level, the most likely perturbations affecting the basin will be those resulting from climate change. Most scientists agree on the likelihood of climate change occurring, which is attributed directly or indirectly to human activity, and many argue that some of its effects can already be observed. Major characteristics of climate change are expected to be increased average global temperatures and an increase in the frequency and magnitude of storms (NAST 2000; Mote 2001; NRC 2001). It is very difficult to predict the impact of climate change in a particular region such as the Coeur d'Alene River basin. Some areas are likely to experience increased storms and precipitation, others a warmer dryer climate.

Climate change models focusing on the Pacific Northwest generally predict warmer temperatures and increased winter precipitation by the mid-21st century (Climate Impacts Group 2004). The modelers predict that the following changes would occur (Hamlet and Lettenmaier 1999; Mote et al. 1999, 2003; Miles et al. 2000; Climate Impacts Group 2004; Palmer et al. 2004):

- Increase the amount of winter precipitation falling as rain rather than snow.
- Increase winter stream flow.
- Increase winter flood risks in transient (rain/snow mix) basins.
- Reduce the amounts of water stored as snow, particularly in mid-elevation transient (rain/snow mix) basins.

- Induce earlier snow melt and advance peak runoff earlier into the spring.
- Decrease late spring and summer stream flows.

Other studies have suggested that the increased winter flood flows will produce greater channel scour and sediment load in rivers (Hamlet et al. 2004) and that the early snow melt and dry summers may increase the number and size of forest fires, as well as lead to drought-stressed forests subject to disease and insect infestation (Service 2004). Drier summers could reduce the basin's ability to support its current rich vegetation. One result could be increased wind erosion of contaminated sediments, increasing human health risks from their inhalation.

It is difficult, often impossible, to predict what perturbations will occur and, if they do occur, what effects they might have on the Coeur d'Alene River basin. Nevertheless, it is prudent to keep such possibilities in mind in the process of evaluating and designing remedies that are expected to protect human health and the environment in the basin for the future.

## REFERENCES

- Abbott, A.M. 2000. Land Management and Flood Effects on the Distribution and Abundance of Cutthroat Trout in the Coeur d'Alene River Basin, Idaho. M.S. Thesis, University of Idaho, Moscow, ID. 86 pp.
- Balistrieri, L.S., A.A. Bookstrom, S.E. Box, and M. Ikramuddin. 1998. Drainage From Adits and Tailings Piles in the Coeur d'Alene Mining District, Idaho: Sampling, Analytical Methods, and Results. USGS Open-File Report 98-127. Menlo Park, CA: U.S. Department of the Interior, U.S. Geological Survey. 19 pp.
- Balistrieri, L.S., S.E. Box, A.A. Bookstrom, R.L. Hooper, and J.B. Mahoney. 2002a. Impacts of historical mining in the Coeur d'Alene River Basin. Pp. 1-34 in *Pathways of Metal Transfer from Mineralized Sources to Bioreceptors: A Synthesis of the Mineral Resources Program's Past Environmental Studies in the Western United States and Future Research Directions*, L.S. Balistrieri, L.L. Stillings, R.P. Ashley, and L.P. Gough, eds. U.S. Geological Survey Bulletin 2141. Reston, VA: U.S. Department of the Interior, U.S. Geological Survey [online]. Available: <http://geopubs.wr.usgs.gov/bulletin/b2191/> [accessed Dec. 1, 2004].
- Balistrieri, L.S., S.E. Box, and A.A. Bookstrom. 2002b. A geoenvironmental model for polymetallic vein deposits: A case study in the Coeur d'Alene mining district and comparisons with drainage from mineralized deposits in the Colorado Mineral Belt and Humboldt Basin, Nevada. Pp. 143-160 in *Progress on Geoenvironmental Models for Selected Mineral Deposit Types*, R.R. Seal, and N.K. Foley, eds. U.S. Geological Survey Open-File Report 02-195. Reston, VA: U.S. Department of the Interior, U.S. Geological Survey [online]. Available: <http://pubs.usgs.gov/of/2002/of02-195/> [accessed Dec. 1, 2004].
- Barton, G.J. 2002. Dissolved Cadmium, Zinc, and Lead Loads from Ground-Water Seepage Into the South Fork Coeur d'Alene River System, Northern Idaho, 1999. *Water-Resources Investigations Report 01-4274*. Boise, ID: U.S. Department of the Interior, U.S. Geological Survey. 130 pp [online]. Available: <http://purl.access.gpo.gov/GPO/LPS39228> [accessed Dec. 1, 2004].
- Baxter, G.T., and M.D. Stone. 1995. *Fishes of Wyoming*. Cheyenne, WY: Wyoming Game and Fish Department. 290 pp.

- Beckwith, M.A., C. Berenbrock, and R.L. Backsen. 1996. Magnitude of Floods in Northern Idaho, February 1996. U.S. Geological Survey Fact Sheet FS-222-96. Reston, VA: U.S. Department of the Interior, U.S. Geological Survey. 2 pp.
- Bennett, E.H. 1994. A History of the Bunker Hill Superfund Site, Kellogg, Idaho. Prepared for the Pacific Northwest Metals Conference, April 9, 1994, Spokane, WA. 31 pp.
- Berenbrock, C. 2002. Estimating the Magnitude of Peak Flows at Selected Recurrence Intervals for Streams in Idaho. U.S. Geological Survey Open-File Report 02-4170. Boise, ID: U.S. Department of the Interior, U.S. Geological Survey. 52 pp [online]. Available: <http://purl.access.gpo.gov/GPO/LPS41703> [accessed Dec. 1, 2004].
- Bookstrom, A.A., S.E. Box, B.L. Jackson, T.R. Brandt, P.D. Derkey, and S.R. Munts. 1999. Digital Map of Surficial Geology, Wetlands, and Deepwater Habitats, Coeur d'Alene Valley, Idaho. U. S. Geological Survey Open-File Report 99-548. Reston, VA: U.S. Department of the Interior, U.S. Geological Survey [online]. Available: <http://wrgis.wr.usgs.gov/open-file/of99-548/> [accessed Dec. 1, 2004].
- Bookstrom, A.A., S.E. Box, J.K. Campbell, K.I. Foster, and B.L. Jackson. 2001. Lead-Rich Sediments, Coeur d'Alene River Valley, Idaho: Area, Volume, Tonnage, and Lead Content. U.S. Geological Survey Open-File report 01-140. Menlo Park, CA: U.S. Department of the Interior, U.S. Geological Survey [online]. Available: <http://geopubs.wr.usgs.gov/open-file/of01-140/> [accessed Dec. 1, 2004].
- Bookstrom, A.A., S.E. Box, R.S. Fousek, J.C. Wallis, H.Z. Kayser, and B.L. Jackson. 2004a. Baseline and Historical Depositional Rates and Lead Concentrations, Floodplain Sediments: Lower Coeur d'Alene River, Idaho. U.S. Geological Survey Open-File Report 2004-1211. U.S. Department of the Interior, U.S. Geological Survey, Spokane, WA [online]. Available: <http://pubs.usgs.gov/of/2004/1211/> [accessed June 23, 2005].
- Bookstrom, A.A., S.E. Box, and R. Fousek. 2004b. Baseline Deposition Rates, Lead-Rich Sediment, Coeur d'Alene (CdA) River Floodplain, Idaho. Geological Society of America Abstracts with Programs 36(4):24 [online]. Available: [http://gsa.confex.com/gsa/2004RM/finalprogram/abstract\\_72984.htm](http://gsa.confex.com/gsa/2004RM/finalprogram/abstract_72984.htm) [accessed Dec. 1, 2004].
- Bornschein, R.L., P. Succop, K.N. Dietrich, C.S. Clark, S. Que Hee, and P.B. Hammond. 1985. The influence of social and environmental factors on dust lead, hand lead, and blood lead levels in young children. *Environ. Res.* 38(1):108-118.
- Borquez, T. 2001. Engineering Remediation Actions Under Superfund on the Smelterville Flats, Shoshone County, Idaho (poster abstract). The Annual International Conference on Contaminated Soils, Sediments and Water, October 22, 2001, University of Massachusetts [online]. Available: <http://www.umasssoils.com/posters2001/> [accessed March 20, 2005].
- Box, S.E. 2004. Metal Enriched Sediment in the Coeur d'Alene River Basin. Presentation at the Third Meeting on Superfund Site Assessment and Remediation in the Coeur d'Alene River Basin, June, 17-18, 2004, Coeur d'Alene, ID.
- Box, S.E., and J.C. Wallis. 2002. Surficial Geology Along the Spokane River, Washington and Its Relationship to the Metal Content of Sediments (Idaho-Washington Stateline to Latah Creek Confluence). Open File Report 02-126. Spokane, WA: U.S. Department of the Interior, U.S. Geological Survey [online]. Available: <http://geopubs.wr.usgs.gov/open-file/of02-126/> [accessed March 21, 2005].
- Box, S.E., A.A. Bookstrom, L.S. Balistrieri, and M. Ikramuddin. 1997. Sources and processes of dissolved metal loading, Coeur d'Alene River, Idaho [abstract]. Inland Northwest Water Resources Conference, April 1997, Spokane, WA.
- Box, S.E., A.A. Bookstrom, and W.N. Kelley. 1999. Surficial Geology of the Valley of the South Fork of the Coeur d'Alene River, Idaho, Draft Version, U.S. Geological Survey, Spokane, WA. October 4, 1999. (Document ID 1110378 in Bunker Hill Basin-Wide Remedial Administrative Record, Data CD8. U.S. Environmental Protection Agency, Region 10, September 2002.)

- Box, S.E., J.C. Wallis, P.H. Briggs, and Z.A. Brown. 2005. Stream-Sediment Geochemistry in Mining-Impacted Streams: Prichard, Eagle, and Beaver Creeks, Northern Coeur d'Alene Mining District, Northern Idaho. U.S. Geological Survey Scientific Investigation Report SIR 2004-5284 [online]. Available: <http://pubs.usgs.gov/sir/2004/5284/> [accessed June 30, 2005].
- Box, S.E., A.A. Bookstrom, and M. Ikramuddin. In press. Stream-Sediment Geochemistry in Mining-Impacted Streams: Sediment Mobilized by Floods in the Coeur d'Alene-Spokane River Drainage, Idaho and Washington. USGS Scientific Investigation Report SIR 2005-5011. U.S. Department of the Interior, U.S. Geological Survey.
- CBFWA (Columbia Basin Fish and Wildlife Authority). 2001. Coeur d'Alene Subbasin Summary (Including Coeur d'Alene Lake and All Tributaries). Prepared for the Northwest Power Planning Council. March 16, 2001 [online]. Available: <http://www.cbfgwa.org/files/province/mtncol/subsum/031601CoeurAlene.pdf> [accessed Dec. 3, 2004].
- CH2M-Hill. 2004. Dissolved Metal Loading from Groundwater to the South Fork of the Coeur d'Alene River, Bunker Hill Superfund Site, Idaho, Draft Final Report, June, 2004. Work Assignment No. 015-TA-TA-10X9. CH2M Hill Project No. 152210.ET.23. Prepared for U.S. Environmental Protection Agency, Region 10, Seattle, WA, by CH2M Hill, Spokane, WA.
- CH2M-Hill, and URS Corp. 2001. Final Ecological Risk Assessment: Coeur d'Alene Basin Remedial Investigation/Feasibility Study. URS DCN: 4162500.06200.05.a2. CH2M Hill DCN: WKP0041. Prepared for U.S. Environmental Protection Agency, Region 10, Seattle, WA, by CH2M Hill, Bellevue, WA, and URS Corp., White Shield, Inc., Seattle, WA. May 18, 2001.
- Clark, G.M. 2003. Occurrence and Transport of Cadmium, Lead, and Zinc in the Spokane River Basin, Idaho and Washington, Water Years 1999-2001. Water-Resources Investigations Report 02-4183. Boise, ID: U.S. Department of the Interior, U.S. Geological Survey [online]. Available: <http://id.water.usgs.gov/PDF/wri024183/index.html> [accessed Dec. 1, 2004].
- Clark, G.M., and P.F. Woods. 2001. Transport of Suspended and Bedload Sediment at Eight Stations in the Coeur d'Alene River Basin, Idaho. U. S. Geological Survey Open-File Report 00-472. Boise, ID: U.S. Department of the Interior, U.S. Geological Survey [online]. Available: <http://purl.access.gpo.gov/GPO/LPS46003> [accessed Dec. 1, 2004].
- Climate Impacts Group. 2004. Overview of Climate Change Impacts in the U.S. Pacific Northwest. Background paper prepared for the West Coast Governors' Climate Change Initiative, by Climate Impacts Group, University of Washington, Seattle, WA. July 29, 2004. 13 pp [online]. Available: <http://www.cses.washington.edu/db/pdf/cigoverview353.pdf> [accessed Dec. 17, 2004].
- Coeur d'Alene Mines Corporation. 2004. Properties, Silver Valley, Idaho [online]. Available: [http://www.coeur.com/property\\_silvervalley.html](http://www.coeur.com/property_silvervalley.html) [accessed Dec. 7, 2004].
- Cummins, K.W., and M.J. Klug. 1979. Feeding ecology of stream invertebrates. *Ann. Rev. Ecol. Syst.* 10:147-172 [online]. Available: <http://www.usu.edu/buglab/aqent5550/Readings/AnnReview%20Ecology%20Cummins%20and%20Klug%201979%20Feeding.pdf> [accessed Dec. 1, 2004].
- Dames and Moore. 1991. Bunker Hill RI/FS Report, Task 3, Revised Final Hydrogeologic Assessment, Vol. 1. Prepared for U.S. Environmental Protection Agency, Region 10, by Dames and Moore, Denver, CO. June 11, 1991.
- Davies, P.H., J.P. Goettl Jr., J.R. Sinley, and N.F. Smith. 1976. Acute and chronic toxicity of lead to rainbow trout *Salmo gairdneri*, in hard and soft water. *Water Res.* 10(3):199-206.
- Dawson, K. 1998. Clarification of CIA Seeps Memo. Memorandum to Don Heinle, CH2M-Hill, from Karen Dawson, SEA. July 20, 1998.
- Di Toro, D.M. 2001. *Sediment Flux Modeling*. New York: Wiley.

- Dillon, F.S., and C.A. Mebane. 2002. Development of Site-Specific Water Quality Criteria for the South Fork Coeur d'Alene River, Idaho: Application of Site-Specific Water Quality Criteria Developed in the Headwater Reaches to Downstream Waters. Prepared for the Idaho Department of Environmental Quality, Boise, ID, by WindWard Environmental, Seattle, WA. December 13, 2002. 95 pp.
- EPA (U.S. Environmental Protection Agency). 2000. First Five-Year Review of the Non-Populated Area Operable Unit, Bunker Hill Mining and Metallurgical Complex, Shoshone County, Idaho [online]. Available: <http://www.epa.gov/r10earth/offices/oec/First%205-Year%20Review%20Non-Pop.pdf> [accessed Nov. 29, 2004].
- EPA (U.S. Environmental Protection Agency). 2001. The U.S. Environmental Protection Agency Proposes to Reissue a Wastewater Discharge Permit to Coeur Silver Valley, Inc, and Coeur and Galena Mines and Mills, Wallace, ID, and the State of Idaho Proposes to Certify the Permit. Fact Sheet for Revised Draft Permit. U.S. Environmental Protection Agency, Region 10 [online]. Available: <http://yosemite.epa.gov/R10/water.nsf/0/94fadbd4dc7bd125588256a1d004adb40?OpenDocument> [accessed March 16, 2005].
- EPA (U.S. Environmental Protection Agency). 2002. The Bunker Hill Mining and Metallurgical Complex: Operable Unit 3, Record of Decision. U.S. Environmental Protection Agency, Region 10. September 2002 [online]. Available: [http://yosemite.epa.gov/.../cbc45a44fa1ede3988256ce9005623b1/\\$FILE/ATTBRN4D/Part%201%20Declaration.pdf](http://yosemite.epa.gov/.../cbc45a44fa1ede3988256ce9005623b1/$FILE/ATTBRN4D/Part%201%20Declaration.pdf) [accessed Dec. 1, 2004].
- EPA (U.S. Environmental Protection Agency). 2003. Review of Metals Action Plan; An EPA Science Advisory Board Report. EPA-SAB-EC-LTR-03-001. Science Advisory Board, U.S. Environmental Protection Agency, Washington, DC [online]. Available: <http://www.epa.gov/sab/pdf/ecl03001.pdf> [accessed Dec. 1, 2004].
- EPA (U.S. Environmental Protection Agency). 2004a. Framework for Metals Risk Assessment. EPA/630/P-04/068a. Risk Assessment Forum, U.S. Environmental Protection Agency, Washington, DC. July 2004 [online]. Available: <http://cfpub2.epa.gov/ncea/raf/recordisplay.cfm?deid=56752> [accessed Dec. 1, 2004].
- EPA (U.S. Environmental Protection Agency). 2004b. EPA Responses to NAS Questions (different dates).
- EPA (U.S. Environmental Protection Agency). 2004c. Basin Bulletin, A Quarterly Review of Cleanup in the Coeur d'Alene River Basin. Issue No. 5, Spring 2004.
- Farag, A.M., D.F. Woodward, J.N. Goldstein, W. Brumbaugh, and J.S. Meyer. 1998. Concentrations of metals associated with mining waste in sediments, biofilm, benthic macroinvertebrates, and fish from the Coeur d'Alene River basin, Idaho. *Arch. Environ. Contam. Toxicol.* 34(2):119–127.
- Farag, A.M., D.F. Woodward, W. Brumbaugh, J.N. Goldstein, E. McConnell, C. Hogstrand, and F. Barrows. 1999. Dietary effects of metals-contaminated invertebrates from the Coeur d'Alene River, Idaho, on cutthroat trout. *Trans. Am. Fish. Soc.* 128(4):578–592.
- Gillerman, V.S., and E.H. Bennett. 2004. Annual mining review 2003: State activities—Idaho. *Min. Eng.* 56(5):64–68.
- Grosbois, C.A., A.J. Horowitz, J.J. Smith, and K.A. Elrick. 2001. The effect of mining and related activities on the sediment-trace element geochemistry of Lake Coeur d'Alene, Idaho, U.S.A. Part III. Downstream effects: The Spokane River basin. *Hydrol. Process.* 15(5):855–875.
- Hamlet, A.F., and D.P. Lettenmaier. 1999. Effects of climate change on hydrology and water resources in the Columbia River Basin. *J. Am. Water Resour. Assoc.* 35(6):1597–1623.
- Hamlet, A.F., P.W. Mote, and D. P. Lettenmaier. 2004. Effects of Climate Variability and Change on Natural Streamflows and Water Resources Management in the Columbia River Basin. Presentation to Climate Impacts Group Workshop; Climate Impacts on Salmon Management and Recovery in the Columbia River Basin, September 21, 2004, Portland, OR [online]. Available: [http://www.hydro.washington.edu/Lettenmaier/Presentations/2004/hamlet\\_salmon\\_workshop\\_sept\\_2004.ppt](http://www.hydro.washington.edu/Lettenmaier/Presentations/2004/hamlet_salmon_workshop_sept_2004.ppt) [accessed Dec. 17, 2004].

- Hardy, R. 2004. Union Pacific Railroad Wallace-Mullan Branch Cercla Response Action Coeur d'Alene Basin, Idaho. Presentation at the Second Meeting on Superfund Site Assessment and Remediation in the Coeur d'Alene River Basin, April 15, 2004, Coeur d'Alene, ID.
- Harrington, J.M., S.E. Fendorf, B.W. Wielinga, and R.F. Rosenzweig. 1999. Response to Comment on "Phase Associations and Mobilization of Iron and Trace Elements in Coeur d'Alene Lake, Idaho." *Environ. Sci. Technol.* 33(1):203-204.
- Hart, P., and I. Nelson. 1984. Mining Town. Seattle, WA: University of Washington Press.
- Harvey, G.W. 2000. Monitoring Results on the Effectiveness of Trace (Heavy) Metals Removal Projects at the Interstate Mill and Canyon Creek Sites. Idaho Department of Environmental Quality, Coeur d'Alene Regional Office, Coeur d'Alene, ID. 17 pp.
- Harvey, G.W. 2002. South Fork Coeur d'Alene River Sediment Subbasin Assessment and Total Maximum Daily Load. Coeur d'Alene Regional Office, Idaho Department of Environmental Quality, Coeur d'Alene, ID. May 17, 2002. 98 pp.
- Hecla (Hecla Mining Company). 2004. Lucky Friday. Properties, Hecla Mining Company, Coeur d'Alene, ID [online]. Available: <http://www.hecla-mining.com/propLucky.html> [accessed Dec. 6, 2004].
- Hobbs, S.W., and V.C. Fryklund, Jr. 1968. The Coeur d'Alene District, Idaho. Pp. 1417-1435 in *Ore Deposits of the United States, 1933-1967; The Graton-Sales Volume*, Vol. 2, 1st Ed, J.D. Ridge, ed. New York: American Institute of Mining, Metallurgical, and Petroleum Engineers.
- Hobbs, S.W., A.B. Griggs, R.E. Wallace, and A.B. Campbell. 1965. Geology of the Coeur d'Alene District, Shoshone County, Idaho. U.S. Geological Survey Professional Paper 478. Washington, DC: U.S. Government Printing Office. 139 pp.
- Hornig, C.E., D.A. Terpening, and M.W. Bogue. 1988. Coeur d'Alene Basin EPA Water Quality Monitoring (1972-1986). EPA 910/9-88-216. PB89-217962. U.S. Environmental Protection Agency, Region 10, Seattle, WA. September.
- Horowitz, A.J., K.A. Elrick, and R.B. Cook. 1993. Effects of mining and related activities on the sediment trace element geochemistry of Lake Coeur d'Alene, Idaho, USA. Part I: Surface sediments. *Hydrol. Process.* 7:403-423.
- Horowitz, A.J., K.A. Elrick, J.A. Robbins, and R.B. Cook. 1995a. Effect of mining and related activities on the sediment trace element geochemistry of Lake Coeur d'Alene, Idaho, USA. Part II: Subsurface sediments. *Hydrol. Process.* 9:35-54.
- Horowitz, A.J., K.A. Elrick, J.A. Robbins, and R.B. Cook. 1995b. A summary of the effects of mining and related activities on the sediment-trace element geochemistry of Lake Coeur d'Alene, Idaho, USA. *J. Geochem. Explor.* 52:135-144.
- Houck, J.C., and L.L. Mink. 1994. Characterization of a Shallow Canyon Aquifer Contaminated by Mine Tailings and Suggestions for Constructed Wetlands Treatment. Prepared for the Trustees for the Idaho Natural Resources Damage Trust Fund. March 1994. 20 pp.
- Hynes, H. 1970. *The Ecology of Running Waters*. Toronto: University of Toronto Press.
- Idaho Department of Commerce. 2004. County and Community Profiles of Idaho [online]. Available: <http://www.idoc.state.id.us/idcomm/profiles/> [accessed Dec. 2, 2004].
- Idaho Panhandle National Forests. 1987. Idaho Panhandle National Forests Forest Plan Forest Service Northern Region, U.S. Department of Agriculture [online]. Available: <http://www.fs.fed.us/ipnf/eco/manage/forestplan> [accessed Jan. 29, 2005].
- Idaho Panhandle National Forests. 1998. *Toward an Ecosystem Approach: An Assessment of the Coeur d'Alene River Basin*, 1998. Ecosystem Paper No. 4. Idaho Panhandle National Forests.
- Idaho Panhandle National Forests. 2002. Forest Plan, Monitoring and Evaluation Report. [online]. Available: <http://www.fs.fed.us/ipnf/eco/manage/monitoring/fp2002monrpt.pdf> [accessed Dec. 2, 2004].
- Isaacson, A. 2004. Presentation at the Third Meeting on Superfund Site Assessment and Remediation in the Coeur d'Alene River Basin, June 17, 2004, Coeur d'Alene, ID.

- Kennedy, J.H., T.W. La Point, P. Balci, J. Stanley, and Z.B. Johnson. 2003. Model aquatic ecosystems in ecotoxicological research: Considerations of design, implementation, and analysis. Pp. 45-74 in *Handbook of Ecotoxicology*, 2nd Ed, D.J. Hoffman, B.A. Rattner, G.A. Burton, Jr., and J. Cairns, Jr., eds. Boca Raton, FL: Lewis.
- Koller, K., T. Brown, A. Spurgeon, and L. Levy. 2004. Recent developments in low-lead exposure and intellectual impairment in children. *Environ. Health Perspect.* 112(9):987-994.
- Kootenai County. 1998. Kootenai County Flood Mitigation Plan, 1998. Office of Emergency Management, Kootenai County, ID [online]. Available: <http://www.co.kootenai.id.us/departments/disaster/KCFloodMitigationPlan.pdf> [accessed Dec. 2, 2004].
- Kramer, B. 2004. Going up in Kellogg; Real estate prices rise along with gondola as Silver Mountain gains exposure." *Spokane Spokesman Review* (Spokane, WA). February 28, 2004 Saturday Idaho Ed, Section: Main News; P. A1.
- La Point, T.W., S. Melancon, and M. Morris. 1984. Relationships among observed metal concentrations, criteria values, and benthic community structural responses in 15 streams. *J. Water Pollut. Control Fed.* 56:1030-1038.
- Long, K.R. 1998. Production and Disposal of Mill Tailings in the Coeur d'Alene Mining Region, Shoshone County, Idaho: Preliminary Estimates. U.S. Geological Survey Open-File Report 98-595. Tucson, AZ: U.S. Department of the Interior, U.S. Geological Survey. 14 pp.
- Maret, T.R., and D.E. MacCoy. 2002. Fish assemblages and environmental variables associated with hard-rock mining in the Coeur d'Alene River Basin, Idaho. *Trans. Am. Fish. Soc.* 131(5):865-884.
- Miles, E.L., A.K. Snover, A.F. Hamlet, B.M. Callahan, and D.L. Fluharty. 2000. Pacific Northwest regional assessment: The impacts of climate variability and climate change on the water resources of the Columbia River Basin. *J. Am. Water Resour. Assoc.* 36(2):399-420.
- Minshall, G.W., R. Peterson, T. Bott, C. Cushing, K. Cummins, R. Vannote, and J. Sedell. 1992. Stream ecosystem dynamics of the Salmon River, Idaho: An 8th-order system. *J. N. Am. Benthol. Soc.* 11(2):111-137.
- Montgomery, D.R., and J.M. Buffington. 1997. Channel-reach morphology in mountain drainage basins. *Geol. Soc. Am.* 109(5):596-611.
- Mote, P.W. 2001. Scientific Assessment of Climate Change: Global and Regional Scales. Preparatory White Paper for Climate and Water Policy Meeting, Skamania, Washington, July 2001. Climate Impacts Group, University of Washington. 10 pp [online]. Available: [http://www.cses.washington.edu/db/pdf/Mote\\_Scientific\\_Assess98.pdf](http://www.cses.washington.edu/db/pdf/Mote_Scientific_Assess98.pdf) [accessed Dec. 3, 2004].
- Mote, P.W., D.J. Canning, D.L. Fluharty, R.C. Francis, J.F. Franklin, A.F. Hamlet, M. Hershman, M. Holmberg, K.N. Ideker, W.S. Keeton, D.P. Lettenmaier, L.R. Leung, N.J. Mantua, E.L. Miles, B. Noble, H. Parandvash, D.W. Peterson, A.K. Snover, and S.R. Willard. 1999. Impacts of Climate Variability and Change, Pacific Northwest. National Atmospheric and Oceanic Administration, Office of Global Programs, and JISAO/SMA Climate Impacts Group, Seattle, WA. 110 pp.
- Mote, P.W., E.A. Parson, A.F. Hamlet, W.S. Keeton, D. Lettenmaier, N. Mantua, E.L. Miles, D.W. Peterson, D.L. Peterson, R. Slaughter, and A.K. Snover. 2003. Preparing for climate change: The water, salmon, and forests of the Pacific Northwest. *Climatic Change* 61(1-2):45-88.
- NAST (National Assessment Synthesis Team). 2000. Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change. Cambridge: Cambridge University Press [online]. Available: <http://www.gcrio.org/NationalAssessment/foundation.html> [accessed Dec. 3, 2004].
- NRC (National Research Council). 1999. Hardrock Mining on Federal Lands. Washington, DC: National Academy Press.

- NRC (National Research Council). 2001. *Climate Change Science: An Analysis of Some Key Questions*. Washington, DC: National Academy Press. 29 pp.
- NRC (National Research Council). 2003. *Bioavailability of Contaminants in Soils and Sediments: Processes, Tools, and Applications*. Washington, DC: The National Academies Press. 420 pp.
- NRCS (Natural Resources Conservation Service). 2003. ID606 Soil Survey of Kootenai County Area, Idaho. Natural Resources Conservation Service, U.S. Department of Agriculture [online]. Available: [http://www.or.nrcs.usda.gov/pnw\\_soil/idaho/id606.html](http://www.or.nrcs.usda.gov/pnw_soil/idaho/id606.html) [accessed Dec. 3, 2004].
- Palmer, R.N., E. Clancy, N.T. VanRheenen, and M.W. Wiley. 2004. *The Impacts of Climate Change on the Tualatin River Basin Water Supply: An Investigation into Projected Hydrologic and Management Impacts*. Department of Civil and Environmental Engineering, University of Washington, Seattle, WA. 91 pp.
- Pyne, S.J. 2001. *Year of the Fires: The Story of the Great Fires of 1910*. New York, NY: Viking. 322 pp.
- Ransome, F.L., and F.C. Calkins. 1908. *The Geology and Ore Deposits of the Coeur d'Alene District, Idaho*. U.S. Geological Survey Professional Paper 62. Washington, DC: U.S. Government Printing Office. 203 pp.
- Rouse, J.V. 1977. Geohydrologic Conditions in the Vicinity of Bunker Hill Company Waste-Disposal Facilities: Kellogg, Shoshone County Idaho—1976. EPA-330/2-77-006. EPA National Enforcement Investigation Center, Denver CO. March 1977.
- Rust, W.C. 2004. Response to the Statement in the Basin Bulletin's Frequently Asked Question Section. Letter to Sheila M. Eckman, Team Leader, Coeur d'Alene Basin Team, U.S. EPA Region 10, Seattle, WA, from W.C. Rust, Consulting Metallurgist, Wallace, ID. May 23, 2004.
- Service, R.F. 2004. As the west goes dry. *Science* 303(5661):1124-1127.
- Sheldrake, S., and M. Stifelman. 2003. A case study of lead contamination cleanup effectiveness at Bunker Hill. *Sci. Total Environ.* 303(1):105-123.
- Sterling Mining Company. 2004. Sterling Mining Commences Surface Exploration on Sunshine Silver Mine. News Release, September 16, 2004 [online]. Available: <http://www.sterlingmining.com/printables/release91604.html> [accessed Dec. 7, 2004].
- Stratus Consulting, Inc. 2000. Report of Injury Assessment and Injury Determination: Coeur d'Alene Basin Natural Resource Damage Assessment. Prepared for U.S. Department of the Interior, Fish and Wildlife Service, U.S. Department of Agriculture, Forest Service, Coeur d'Alene Tribe, by Stratus Consulting Inc., Boulder, CO. September 2000.
- TerraGraphics. 1990. Risk Assessment Data Evaluation Report (RADER) for the Populated Areas of the Bunker Hill Superfund Site. Prepared by TerraGraphics Environmental Engineering, Inc., Moscow, ID, for U.S. Environmental Protection Agency, Region 10, Seattle, WA. October 18, 1990.
- TerraGraphics. 1996. Draft Groundwater Loading Study, Vol. 1. Prepared for the Idaho Department of Health and Welfare, Division of Environmental Quality, Boise, ID, by TerraGraphics Environmental Engineering, Inc., Moscow, ID. March 1996.
- TerraGraphics. 2000. Final 1999 Five Year Review Report Bunker Hill Site. Prepared for Idaho Department of Health and Welfare Division of Environmental Quality, Boise, ID, by TerraGraphics Environmental Engineering, Inc., Moscow, ID. April 2000.
- TerraGraphics. 2001. Draft 2000 Trend Analysis Of Site-Wide Monitoring Program Bunker Hill Superfund Site, Prepared for the Idaho Department of Health and Welfare, Division of Environmental Quality, Boise, ID by TerraGraphics Environmental Engineering, Inc., Moscow, ID. June 2001 [online]. Available: [http://www.tgenviro.com/WaterQuality/SWMON-TrendAnalysis\\_Draft2.pdf](http://www.tgenviro.com/WaterQuality/SWMON-TrendAnalysis_Draft2.pdf) [accessed March 31, 2005].
- TerraGraphics. 2005. Bunker Hill Water Quality Data-Current Well Data (1997-2003), Query by Map. TerraGraphics Environmental Engineering, Inc. [online]. Available: <http://www.tgenviro.com/WaterQuality/map/index.html> [accessed March 30, 2005].

- URS Greiner, Inc., and CH2M Hill. 2001a. Final (Revision 2) Remedial Investigation Report, Remedial Investigation Report for the Coeur d'Alene Basin Remedial Investigation/Feasibility Study, Vol. 1. Part 7. Summary. URSG DCN 4162500.6659.05a. Prepared for U.S. Environmental Protection Agency, Region 10, Seattle, WA, by URS Greiner, Inc., Seattle, WA, and CH2M Hill, Bellevue, WA. September 2001.
- URS Greiner, Inc., and CH2M Hill. 2001b. Final (Revision 2) Remedial Investigation Report, Remedial Investigation Report for the Coeur d'Alene Basin Remedial Investigation/Feasibility Study, Vol. 1. Part 1. Setting and Methodology. URSG DCN 4162500.6659.05a. Prepared for U.S. Environmental Protection Agency, Region 10, Seattle, WA, by URS Greiner, Inc., Seattle, WA, and CH2M Hill, Bellevue, WA. September 2001.
- URS Greiner, Inc., and CH2M Hill. 2001c. Final (Revision 2) Remedial Investigation Report, Remedial Investigation Report for the Coeur d'Alene Basin Remedial Investigation/Feasibility Study, Vol. 2. Part 2. CSM Unit 1, Upper Watersheds Canyon Creek. URSG DCN 4162500.6659.05a. Prepared for U.S. Environmental Protection Agency, Region 10, Seattle, WA, by URS Greiner, Inc., Seattle, WA, and CH2M Hill, Bellevue, WA. September 2001.
- URS Greiner, Inc., and CH2M Hill. 2001d. Final (Revision 2) Remedial Investigation Report, Remedial Investigation Report for the Coeur d'Alene Basin Remedial Investigation/Feasibility Study, Vol. 3. Part 2. CSM Unit 1, Upper Watersheds Ninemile Creek. URSG DCN 4162500.6659.05a. Prepared for U.S. Environmental Protection Agency, Region 10, Seattle, WA, by URS Greiner, Inc., Seattle, WA, and CH2M Hill, Bellevue, WA. September 2001.
- URS Greiner, Inc., and CH2M Hill. 2001e. Final (Revision 2) Remedial Investigation Report, Remedial Investigation Report for the Coeur d'Alene Basin Remedial Investigation/Feasibility Study, Vol. 10. URSG DCN 4162500.6659.05a. Prepared for U.S. Environmental Protection Agency, Region 10, Seattle, WA, by URS Greiner, Inc., Seattle, WA, and CH2M Hill, Bellevue, WA. September 2001.
- URS Greiner, Inc., and CH2M Hill. 2001f. Final (Revision 2) Remedial Investigation Report, Remedial Investigation Report for the Coeur d'Alene Basin Remedial Investigation/Feasibility Study, Vol. 4. Part 3. CSM Unit 2, Midgradient Watersheds, South Fork Coeur d'Alene River. URSG DCN 4162500.6659.05a. Prepared for U.S. Environmental Protection Agency, Region 10, Seattle, WA, by URS Greiner, Inc., Seattle, WA, and CH2M Hill, Bellevue, WA. September 2001.
- URS Greiner, Inc., and CH2M Hill. 2001g. Final (Revision 2) Remedial Investigation Report, Remedial Investigation Report for the Coeur d'Alene Basin Remedial Investigation/Feasibility Study, Vol. 3. Part 2. CSM Unit 1, Upper Watersheds Pine Creek. URSG DCN 4162500.6659.05a. Prepared for U.S. Environmental Protection Agency, Region 10, Seattle, WA, by URS Greiner, Inc., Seattle, WA, and CH2M Hill, Bellevue, WA. September 2001.
- URS Greiner, Inc., and CH2M Hill. 2001h. Final (Revision 2) Remedial Investigation Report, Remedial Investigation Report for the Coeur d'Alene Basin Remedial Investigation/Feasibility Study, Vol. 4. Part 3. CSM Unit 2, Midgradient Watersheds, North Fork Coeur d'Alene River. URSG DCN 4162500.6659.05a. Prepared for U.S. Environmental Protection Agency, Region 10, Seattle, WA, by URS Greiner, Inc., Seattle, WA, and CH2M Hill, Bellevue, WA. September 2001.
- URS Greiner, Inc., and CH2M Hill. 2001i. Probabilistic Analysis of Post-Remediation Metal Loading Technical Memorandum (Revision 1). URSG DCN 4162500.06778.05.a. Prepared for U.S. Environmental Protection Agency, Region 10, Seattle, WA, By URS Greiner, Inc., Seattle, WA, and CH2M Hill, Bellevue, WA. September 20, 2001.

- URS Greiner, Inc., and CH2M Hill. 2001j. Final (Revision 2) Remedial Investigation Report, Remedial Investigation Report for the Coeur d'Alene Basin Remedial Investigation/Feasibility Study, Vol. 4. Part 4. CSM Unit 3, Lower Coeur d'Alene River. URSG DCN 4162500.6659.05a. Prepared for U.S. Environmental Protection Agency, Region 10, Seattle, WA, by URS Greiner, Inc., Seattle, WA, and CH2M Hill, Bellevue, WA. September 2001.
- URS Greiner, Inc., and CH2M Hill. 2001k. Final (Revision 2) Remedial Investigation Report, Remedial Investigation Report for the Coeur d'Alene Basin Remedial Investigation/Feasibility Study, Vol. 4. Part 5. CSM Unit 4, Coeur d'Alene Lake. URSG DCN 4162500.6659.05a. Prepared for U.S. Environmental Protection Agency, Region 10, Seattle, WA, by URS Greiner, Inc., Seattle, WA, and CH2M Hill, Bellevue, WA. September 2001.
- URS Greiner, Inc., and CH2M Hill. 2001l. Final (Revision 2) Remedial Investigation Report, Remedial Investigation Report for the Coeur d'Alene Basin Remedial Investigation/Feasibility Study, Vol. 4. Part 6. CSM Unit 5, Spokane River. URSG DCN 4162500.6659.05a. Prepared for U.S. Environmental Protection Agency, Region 10, Seattle, WA, by URS Greiner, Inc., Seattle, WA, and CH2M Hill, Bellevue, WA. September 2001.
- URS Greiner/CH2M Hill/Syracuse Research Corporation. 1999. Draft Final Coeur d'Alene Basin RI/FS Expedited Screening Level Risk Assessment for Common Use Areas, Coeur d'Alene River Basin, Idaho. URSG DCN 4162500.4658.04.0. Prepared for U.S. Environmental Protection Agency, Region 10, Seattle, WA, by URS Greiner, Inc., Seattle, WA, CH2M Hill, Bellevue, WA, and Syracuse Research Corporation, North Syracuse, NY. October 18, 1999.
- USACE (U.S. Army Corps of Engineers). 2001. Revised Flood Insurance Study for the Coeur d'Alene River at Cataldo, Idaho. U.S. Army Corps of Engineers, Seattle District, Seattle, WA. April 10, 2001. 13 pp.
- U.S. Census 2004. Data Set: 2000. American FactFinder, U.S. Census Bureau [online]. Available: [http://factfinder.census.gov/home/saff/main.html?\\_lang=en](http://factfinder.census.gov/home/saff/main.html?_lang=en) [accessed Nov. 1, 2004].
- USGS (U.S. Geological Survey). 2004. Monthly Streamflow Statistics for Idaho. USGS 12413500 Couer d'Alene River near Cataldo, ID. NWISWeb Data for Idaho, U.S. Geological Survey [online]. Available: <http://nwis.waterdata.usgs.gov/id/nwis/monthly> [accessed Dec. 6, 2004].
- USMRA (U.S. Mine Rescue Association). 2004. Sunshine Mining Company, Sunshine Mine Kellogg, Shoshone County, Idaho, May 2, 1972-91 Killed [online]. Available: <http://www.usmra.com/saxsewell/sunshine.htm> [accessed Dec. 7, 2004].
- Vannote, R.L., G.W. Minshall, J.R. Cummins, J.R. Sedell, and C.E. Cushing. 1980. The river continuum concept. *Can. J. Fish. Aquat. Sci.* 37:130-137.
- White, B.G. 1998. Diverse tectonism in the Coeur d'Alene Mining District, Idaho. Pp. 254-265 in *Belt Symposium III 1993*, R.B. Berg, ed. Montana Bureau of Mines and Geology Special Publication 112. Butte, MT: Montana Bureau of Mines and Geology.
- Winston, D. 2000. Belt Supergroup stratigraphy, sedimentology, and structure in the vicinity of the Coeur d'Alene Mining District. Pp. 85-94 in *Geologic Field Trips, Western Montana and Adjacent Areas*. S.M. Roberts, and D. Winston, eds. Prepared for Rocky Mountain Section Meeting, Geological Society of America, Missoula, MT, April 15-20, 2000, by University of Montana, Missoula, MT.
- Woods, P.F. 2004. Interaction of Lake Productivity with Trace-Element Contamination: Coeur d'Alene, Idaho. Presentation at the Third Meeting on Superfund Site Assessment and Remediation in the Coeur d'Alene River Basin, June 17, 2004, Coeur d'Alene, ID.
- Woodward, D.F., J.A. Hansen, H. Bergman, E. Little, and A.J. DeLonay. 1995. Brown trout avoidance of metals in water characteristic of the Clark Fork River, Montana. *Can. J. Fish. Aquat. Sci.* 52(9):2031-2037.
- Woodward, D.F., J.N. Goldstein, A.M. Farag, and W.G. Brumbaugh. 1997. Cutthroat trout avoidance of metals and conditions characteristic of a mining waste site: Coeur d'Alene River, Idaho. *Trans. Am. Fish. Soc.* 126(4):699-706.